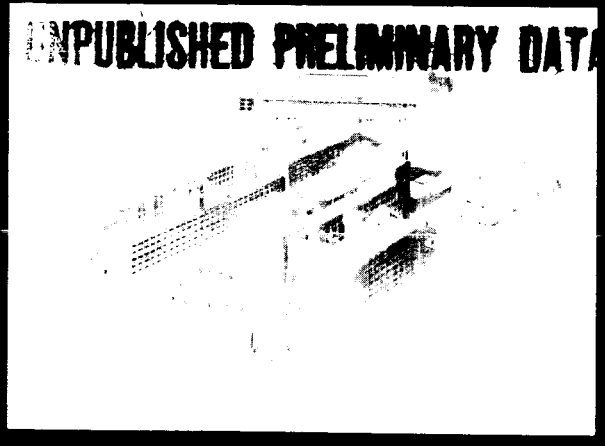

BAUSCH & LOMB INCORPORATED
ROCHESTER 2, NEW YORK

Grating Groove Formation in Au and Au-Ge Alloys

NONR-4277 (00) (X)

Quarterly Report Number 4

Submitted by
Bausch & Lomb Incorporated

January 31, 1965

C. Frank Mooney
Grating Research Section

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CONTENTS

INTRODUCTION

This fourth progress report presents the pictures (Section I) and spectroscopic data (Section 2) for the remainder of the fifty-two test gratings made in 1964, in accord with the contract terms. A "Standard (10/23/64)" reflectance curve that has been used to minimize the effect of the spectral variation of gold optical constants is given and its purpose is described (Section 3). Pictures that describe the substrate (Section 4), the chromium interlayer (Section 5), and the final surface (Section 6) are presented.

A further report is in preparation. It will be prepared to collect the data and pictures for individual rulings on one page. It is hoped that conclusions will be most objectively made from this organization of the information.

1. Electronmicrographs of Au Films and Test Rulings

An electronmicrograph of each gold film used for test ruling and of a representative area of each test ruling are contained in this section. The gold film pictures are at approximately 22000X to survey a larger area of the film. The test ruling pictures are at approximately 30000X in order to examine a smaller area more closely. These magnifications have been used consistently throughout the previous reports of this contract.

There has been one general change worthy of note. Collodion replicas were used for the Au film pictures in earlier reports. All work is now being done with carbon films from aluminum replicas because there is less loss of detail.

The films for rulings 35 through 38 were prepared in the same run. 35 was ruled in normal fashion with the steep face of the groove ahead of the blaze face. The others had the steep face trailing so that the actual groove bottom has not been covered by the Au wave from the next groove. Number 37 was ruled with the steep side trailing, then ruled again without taking the grating out of the engine. The best of the group is the normal ruling, but the quality of the ruling engine used for the test may limit the validity of the double ruling test.

The films for rulings 39 to 42 were again prepared in the same run. The four possible combinations of single vs double ruling and steep side leading or trailing were examined. The normal

case, number 42, again appears to be the best. The double ruling with steep side trailing is better than the corresponding single ruling.

The films for rulings 43 and 44 were prepared in the same run. In this case, the substrates differed. Number 43 had an optical polish; number 44 had a poor shine. In setting up the ruling of these, number 44 was given a thorough burnishing whereas number 43 was not. Both, however, appear to have good groove shape.

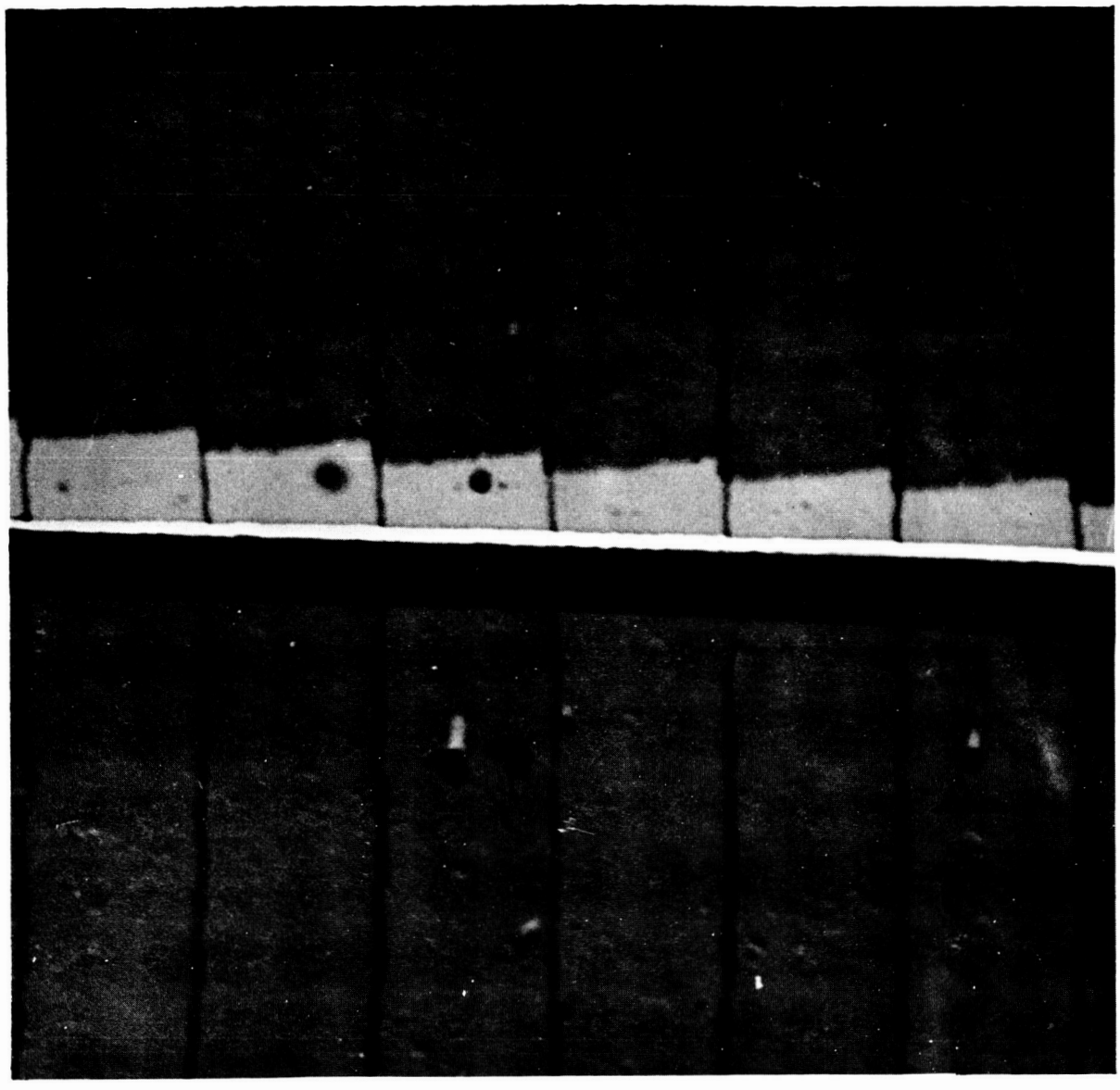
Number 45 was in an alloy film of about .94 Au and .06 Ge. The groove surface appears to be much less smooth submicroscopically than typical Au grooves. It is quite possible that this is an indication that the alloy film is much less malleable than plain Au.

The films for rulings 46 and 47 were prepared in the same run. The substrate for number 46 had an ordinary optical polish. The substrate for number 47 had an exceptional polish (under-liquid process of Herron Optical Co.). The surface of ruling 47 was poorly burnished so no fair comparison of performance can be made. The electronmicroscope must participate at the set-up stage for proper control of groove smoothness.

The films for rulings 48 through 52 were all deposited by Joule heating a molybdenum boat with gold in it. Ruling 48 was in gold that had been deposited rapidly and that had emptied the boat; it was difficult to achieve good grooves, and streaks appeared along them.

Rulings 49 and 50 were also difficult to rule because gold often adhered to the diamond.

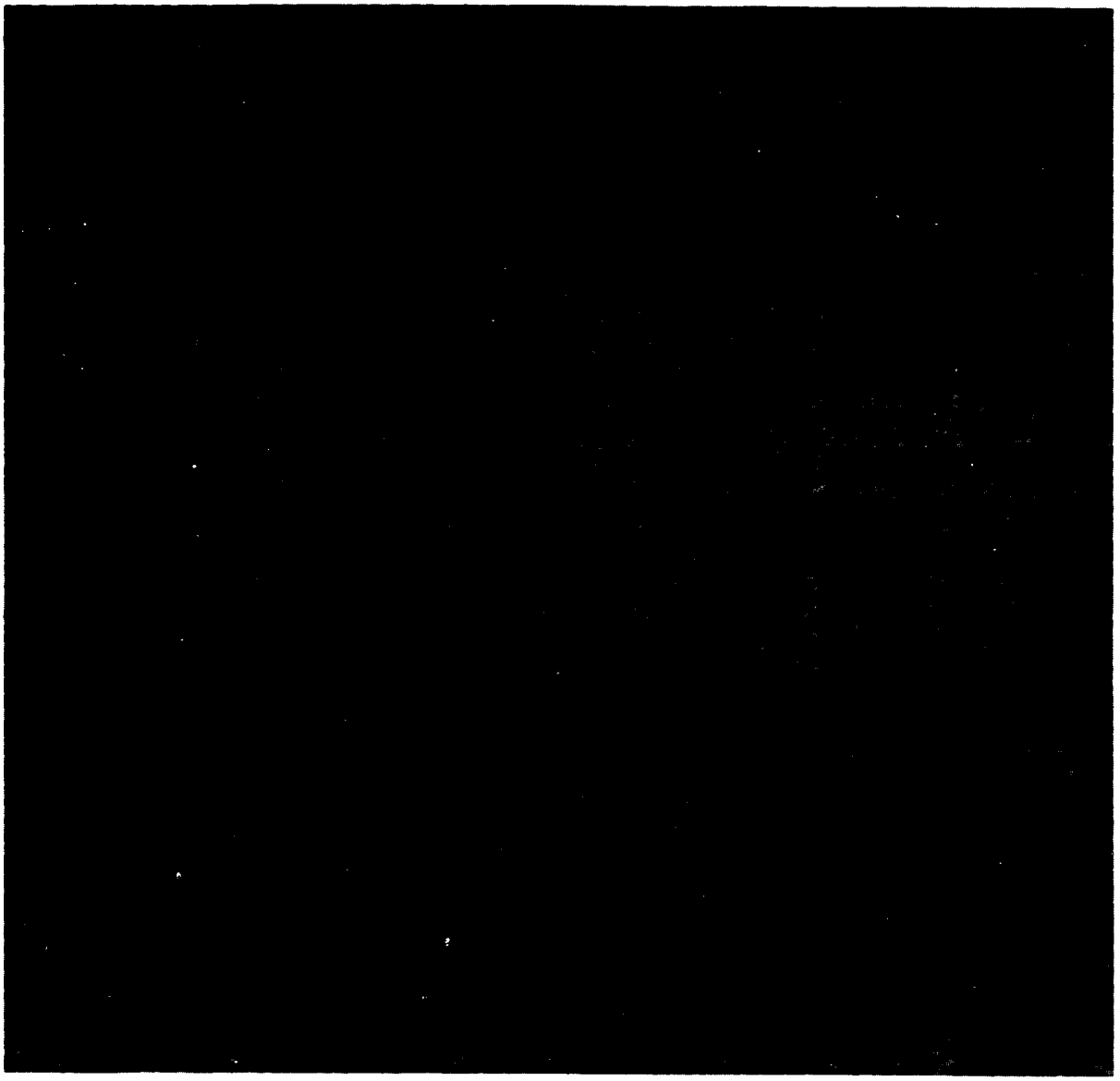
Rulings 51 and 52 were in films made simultaneously; good grooves were much easier to make in these films; there is no indication from the pictures or from the procedure followed why this should be so. The naive notion that gold's chemical inertness would allow it, in contrast to aluminum, to be deposited always the same in spite of large differences of deposition detail was once more refuted, this time for resistance heated vaporization.



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 35.

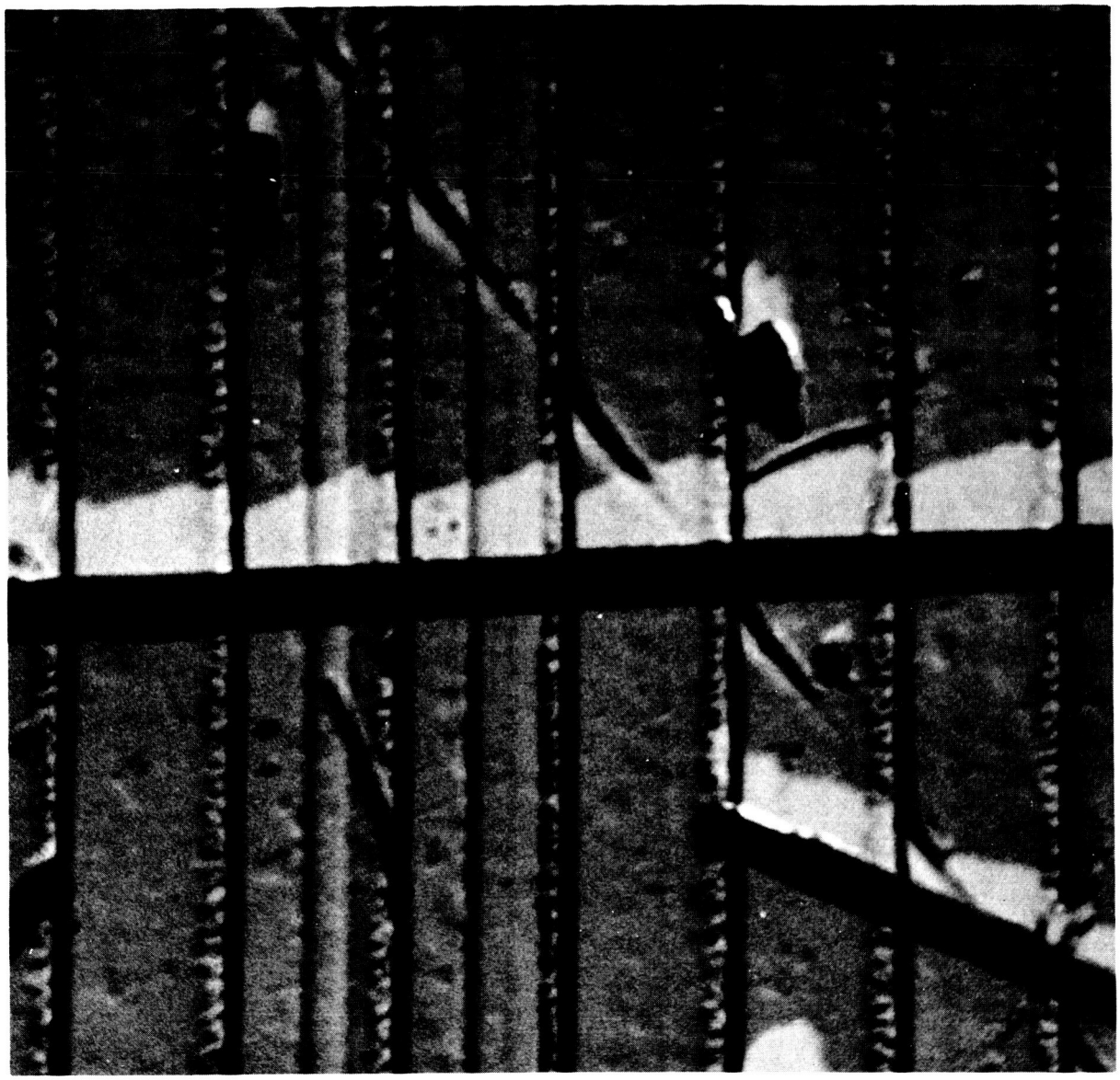
Picture Data		Grating Data	
Film: N147 #6, 10-19-64		Number: N.R.L. 35, 9-9-64	
Replica Substrate: Al Film		Groove Frequency: 1280 gr/mm	
Shadow:	Pt-C	Nominal Slope:	4 deg 35 min
Specimen Film:	C	Meas. Height:	445 A



1μ

Electronmicrograph showing the gold film in which N.R.L. 35, 36, 37, and 38 were ruled.

Picture Data	Evaporation Data
Film: N154 #3, 10-28-64	Mtl./thick: Au/4600Å
Replica Substrate: Al Film	Pressure: 5×10^{-5} mm
Shadow: Pt-C	Deposition Rate: 50 Å/sec
Specimen Film: C	Coating Method: Electron Gun



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 36.

Picture Data

Film: N147 #23, 10-19-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

Grating Data

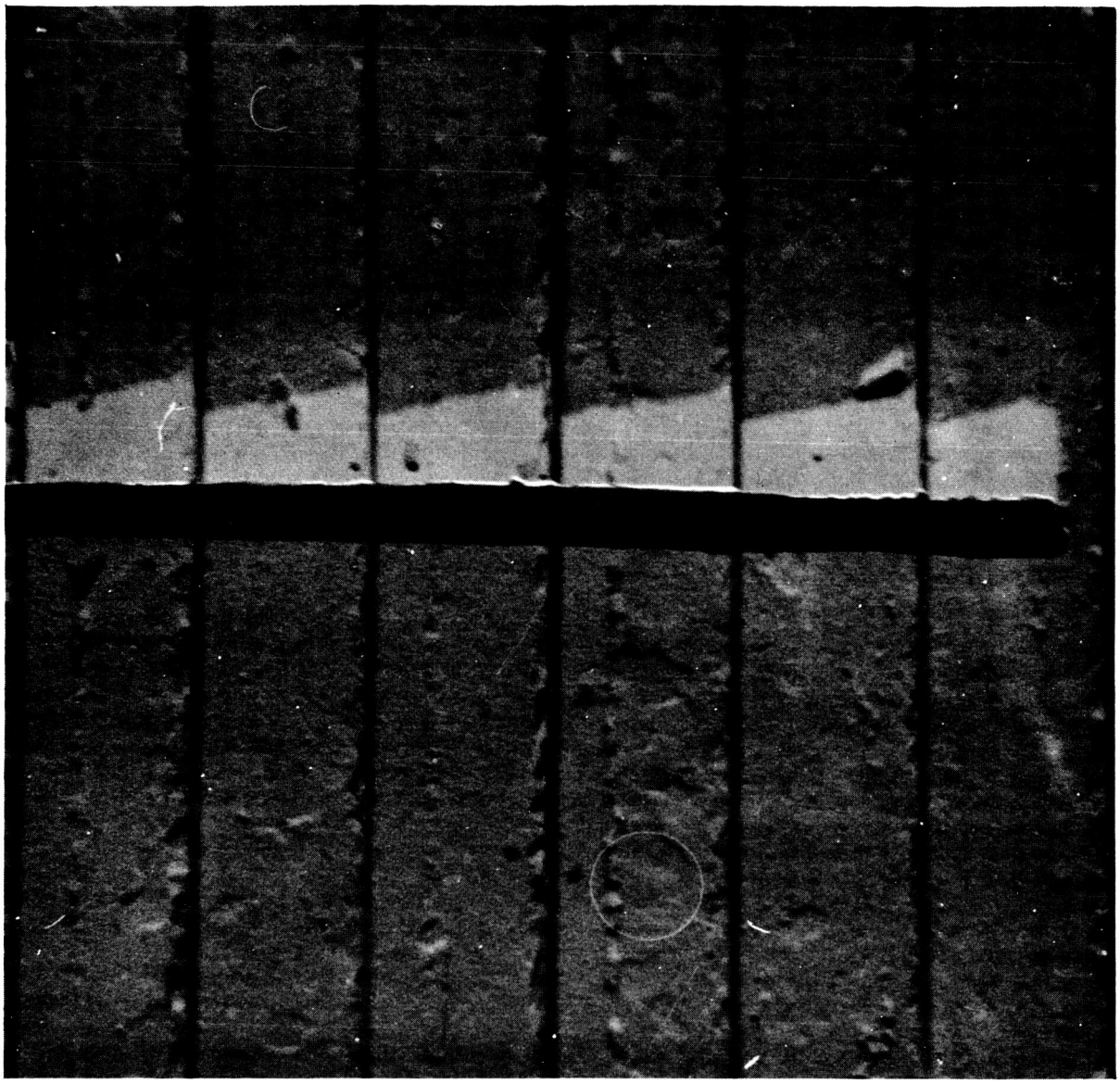
Number: N.R.L. 36, 9-11-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Meas. Height: 760 A

steep side
trailing



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 37.

Film: N148 #12, 10-19-64

Replica Substrate: Al Film

Shadow: Pt-C

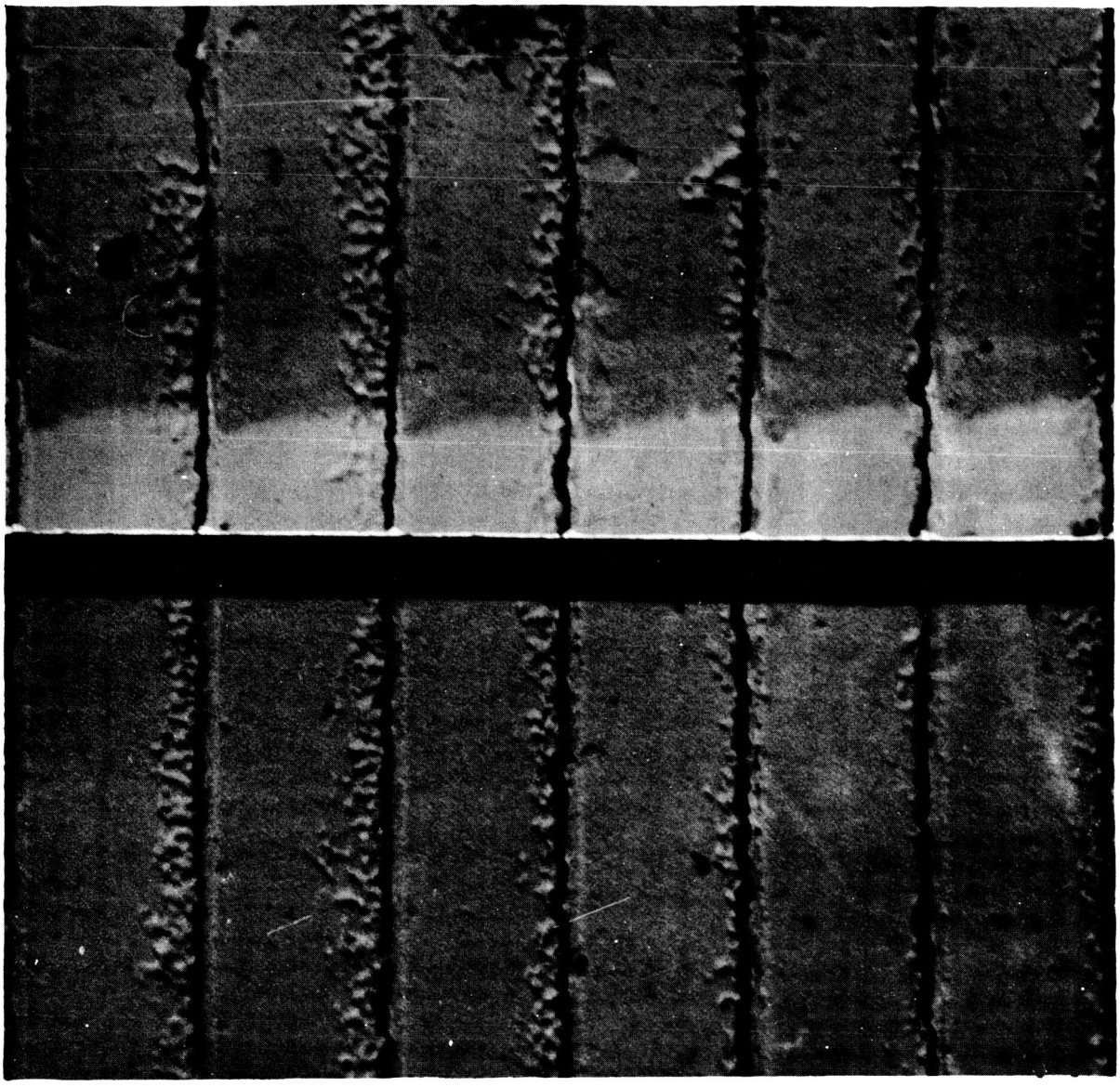
Specimen Film: C

Number: N.R.L. 37, 9-14-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg. 35 min

Meas. Height: 500 A
steep side trail.
double ruling



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 38.

Picture Data

Film: N148 #24, 10-19-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

Grating Data

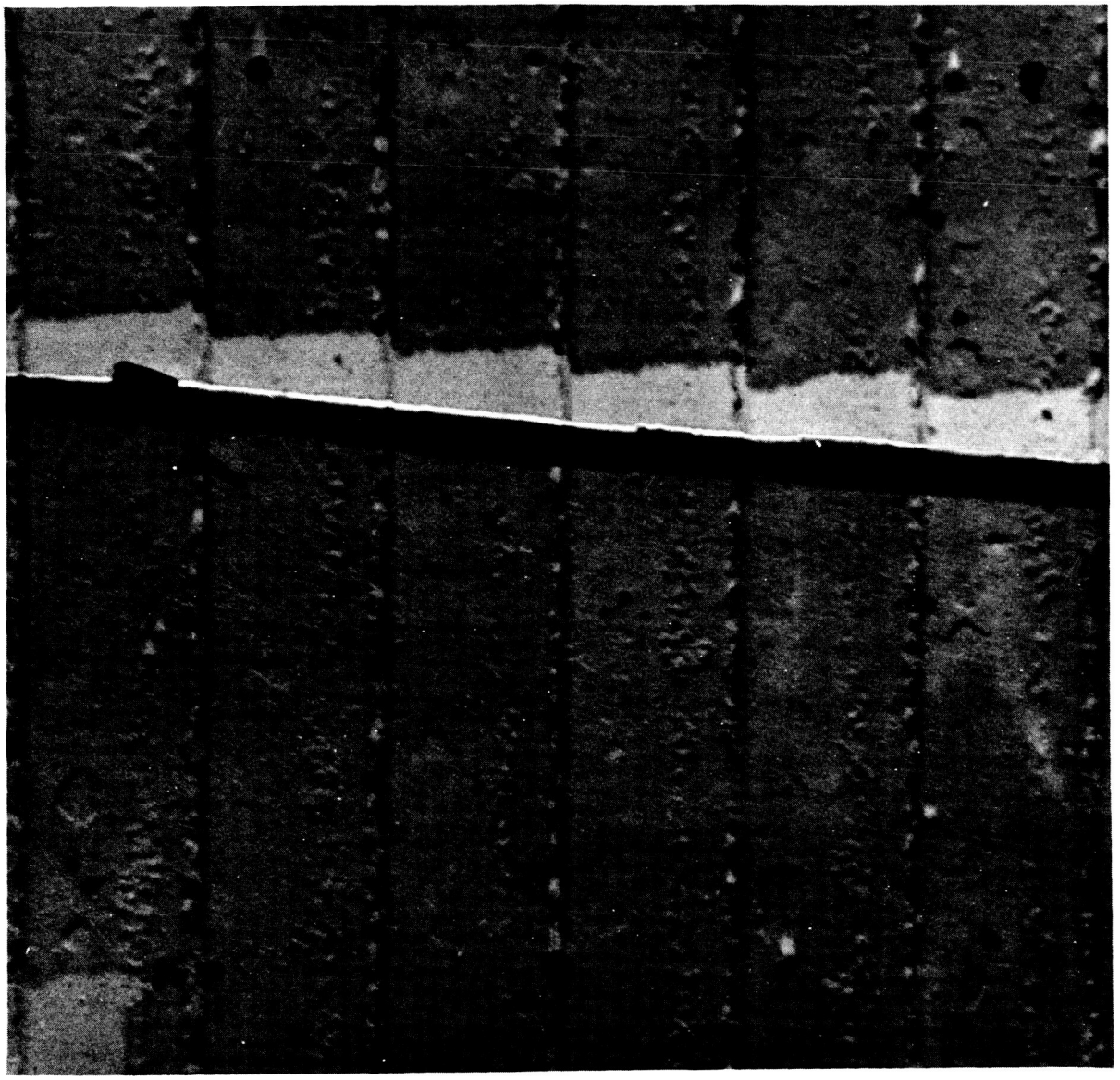
Number: N.R.L. 38, 9-15-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Meas. Height: 470 A

steep side trailing



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 39.

Picture Data

Film: N150 #3, 10-22-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

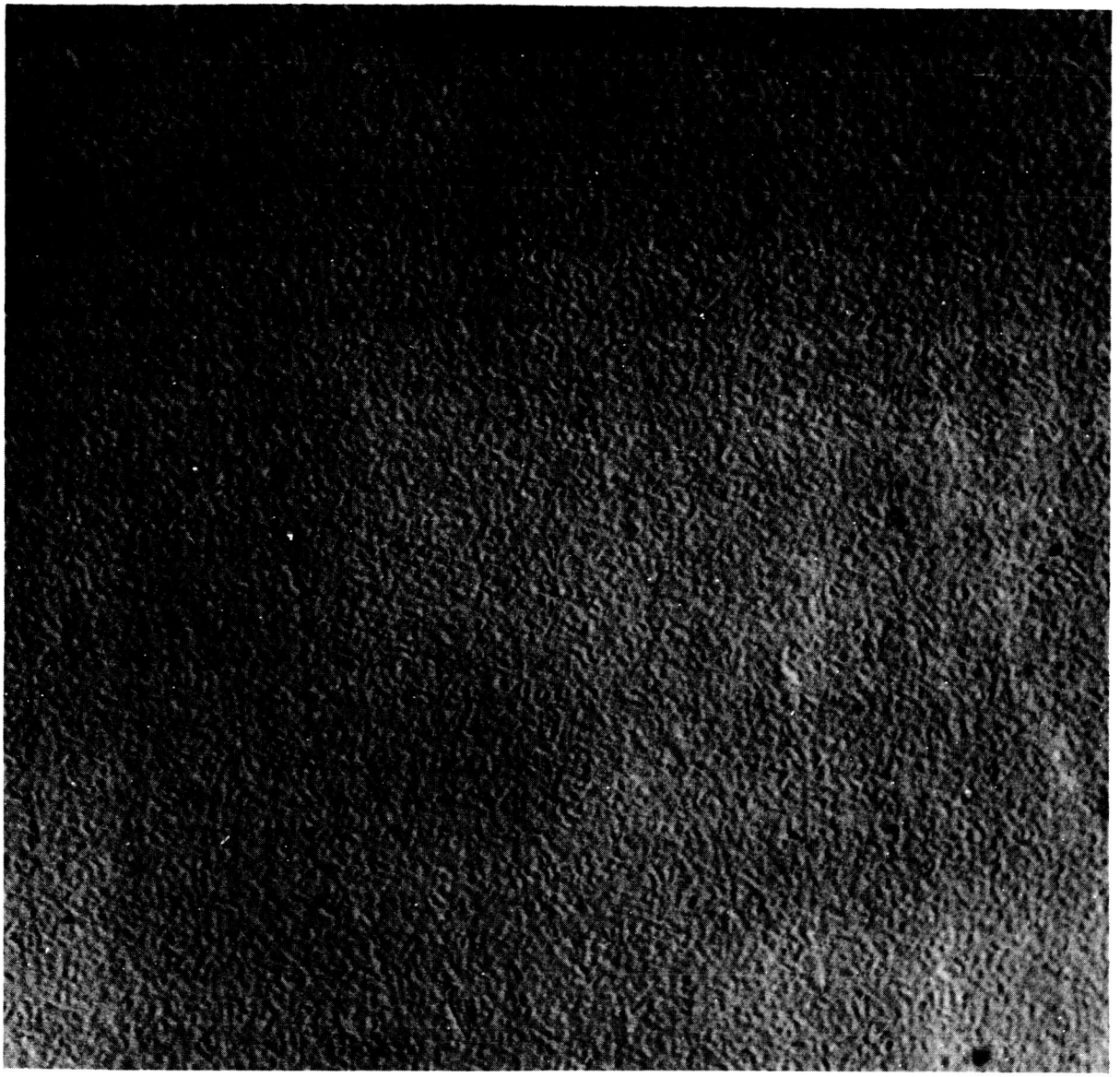
Grating Data

Number: N.R.L. 39, 9-23-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg .35 min

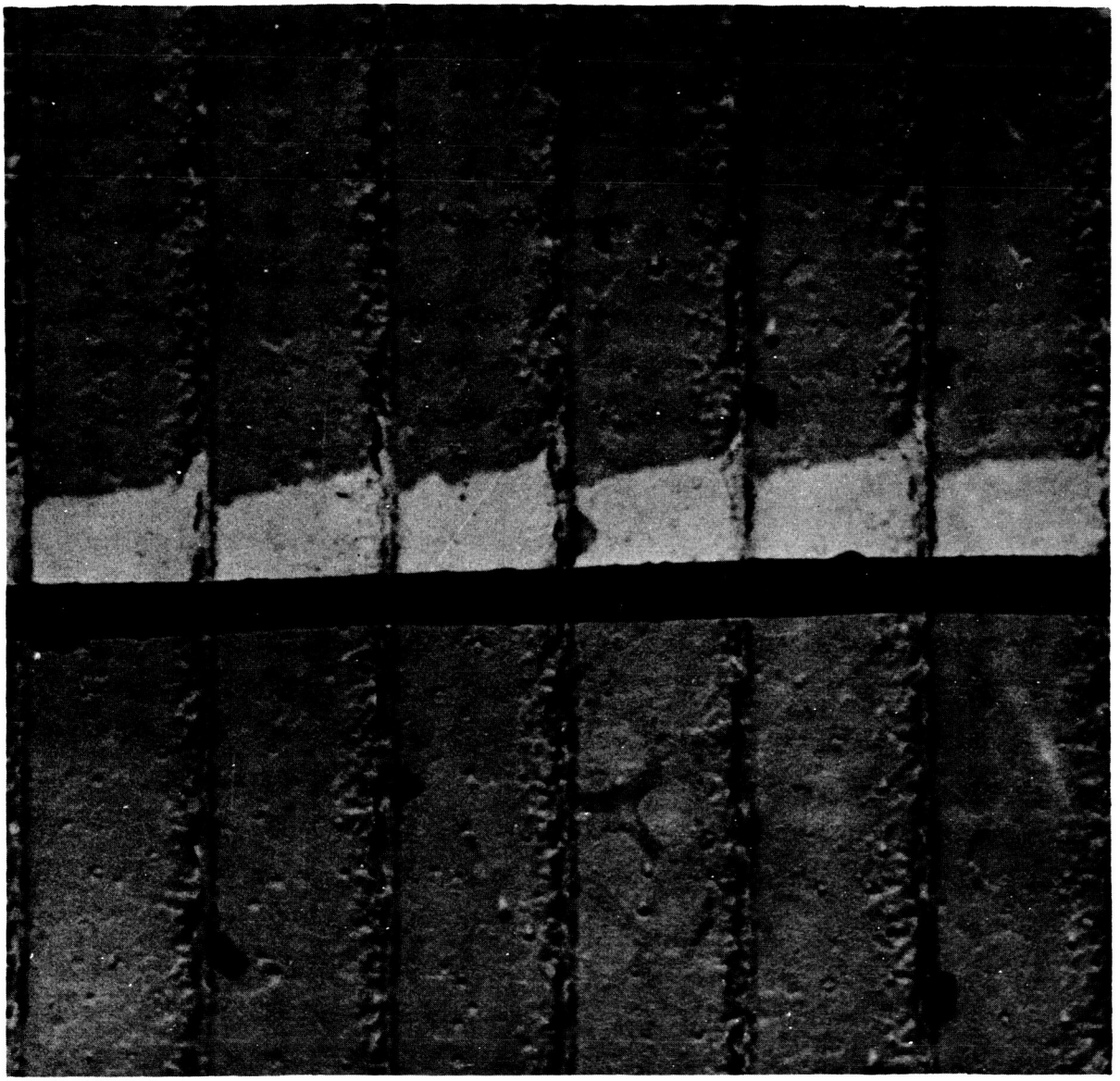
Meas. Height: 390 A
steep side trailing
double ruling.



1μ

Electronmicrograph showing the gold film in which N.R.L. 39, 40, 41, and 42 were ruled.

Picture Data	Evaporation Data
Film: N161 #4, 11-13-64	Mtl./thick: Au/2500Å
Replica Substrate: Al Film	Pressure: 5×10^{-5} mm
Shadow: Pt-C	Deposition Rate: 55Å/sec
Specimen Film: C	Coating Method: Electron Gun



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 40.

Picture Data

Film: N150 #16, 10-22-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

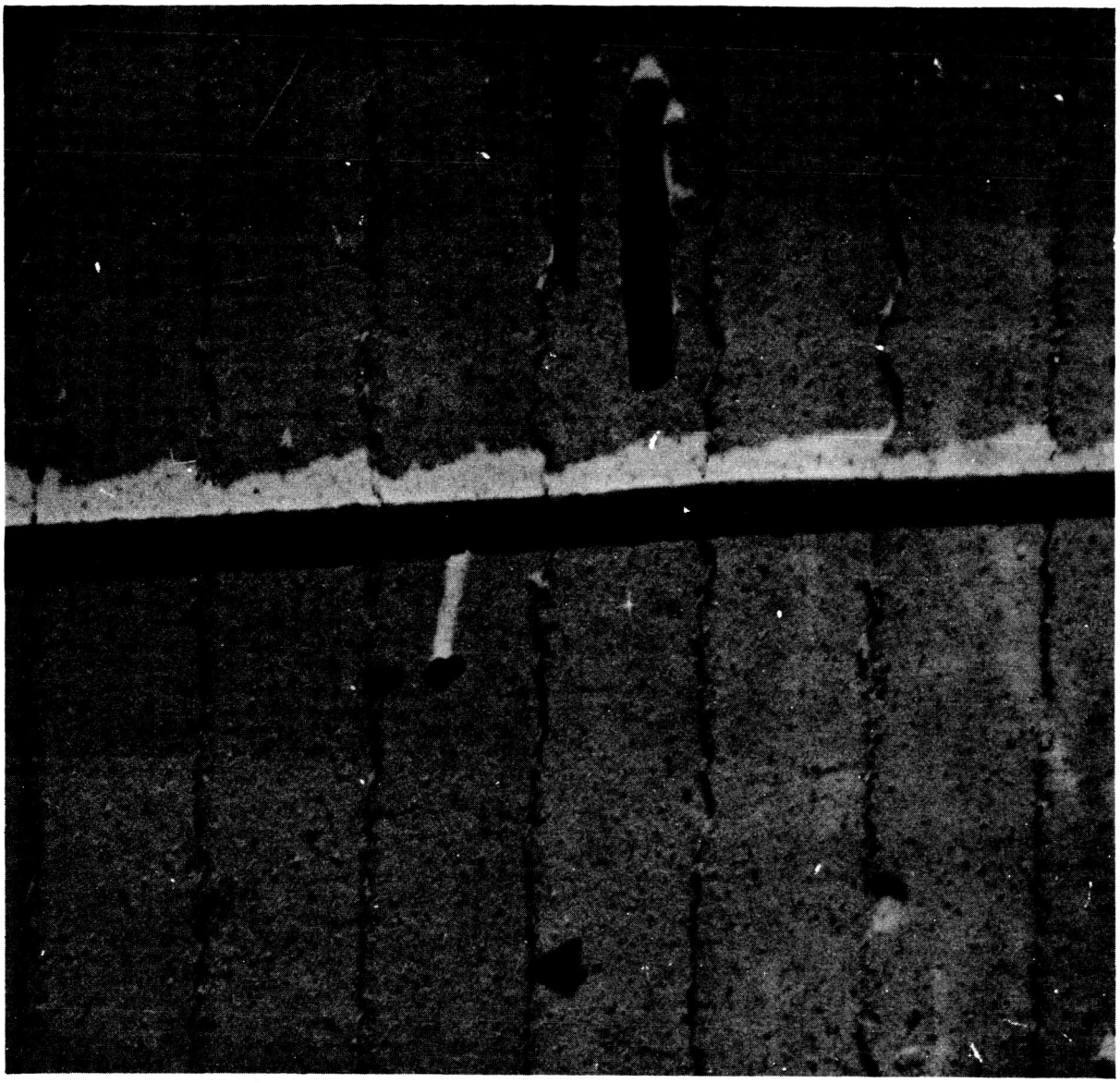
Grating Data

Number: N.R.L. 40, 9-24-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Meas. Height: 500 A
steep side
trailing



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 41.

Picture Data

Film: N151 #9, 10-26-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

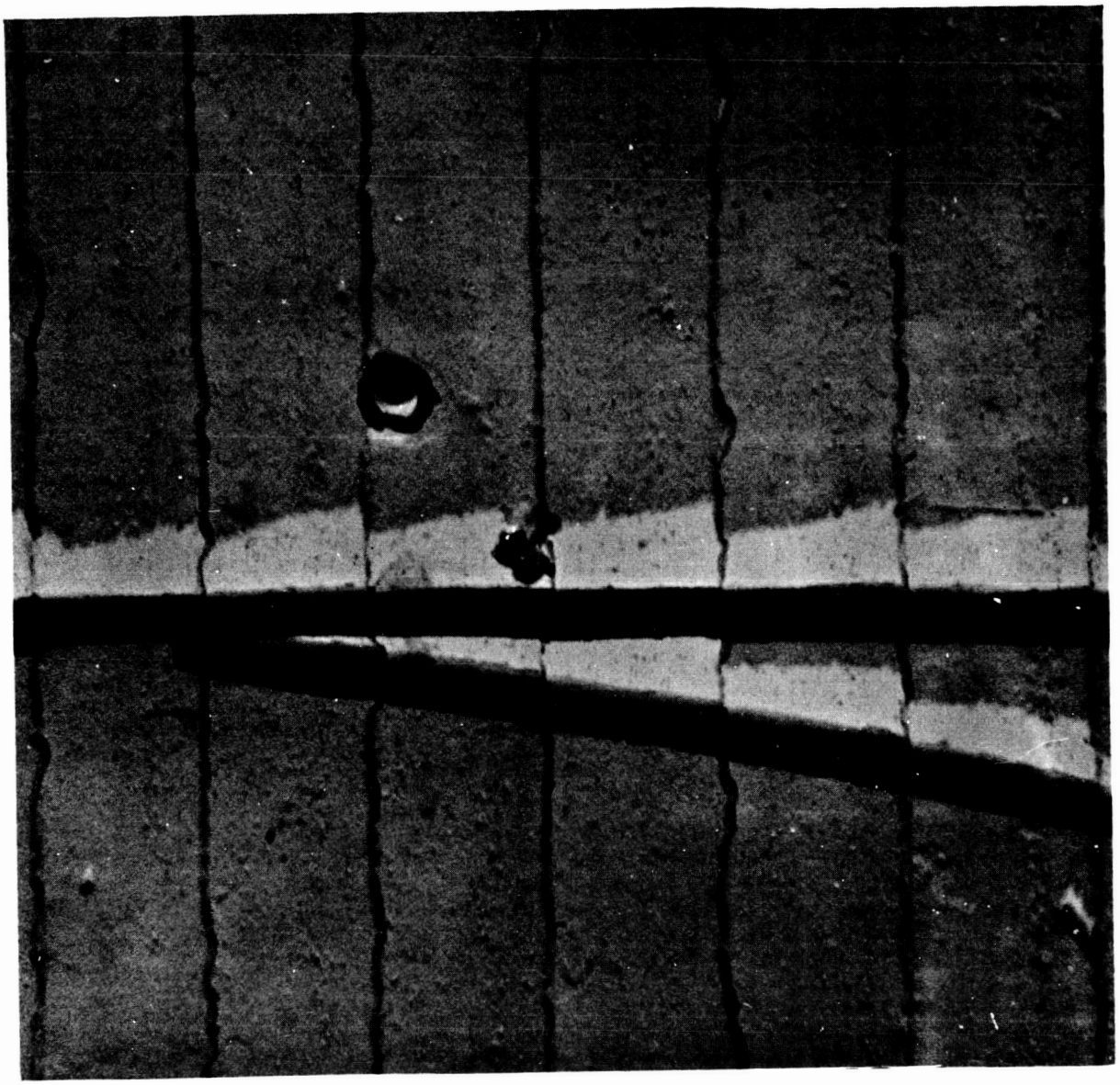
Grating Data

Number: N.R.L. 41, 9-24-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg. 35 min

Meas. Height: 540 A
double ruling



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 42.

Picture Data

Film: N151 #17, 10-26-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

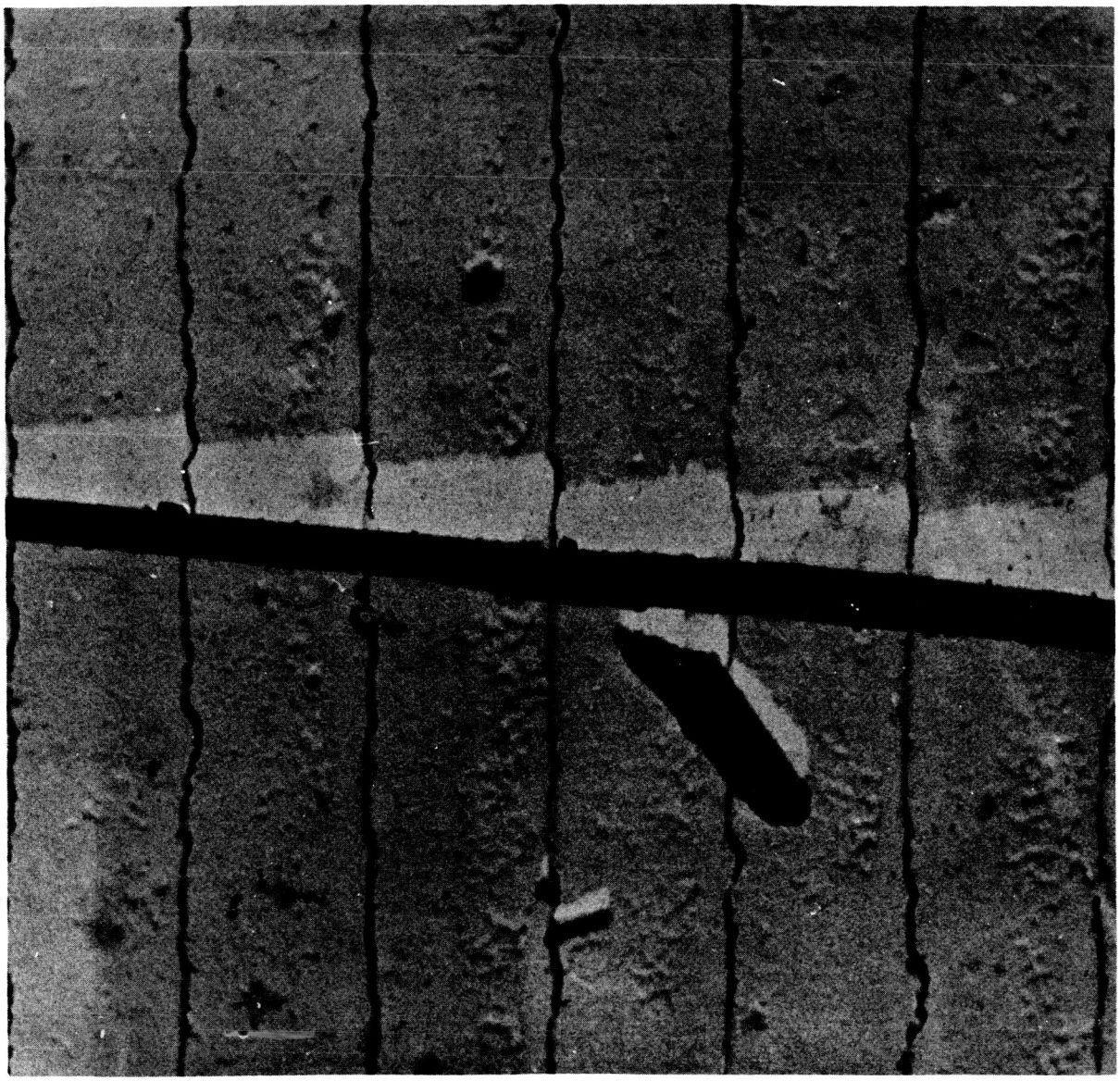
Grating Data

Number: N.R.L. 42, 9-30-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg. 35 min

Meas Height: 450 A



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 43.

Picture Data

Film: N152 #13, 10-2 7-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

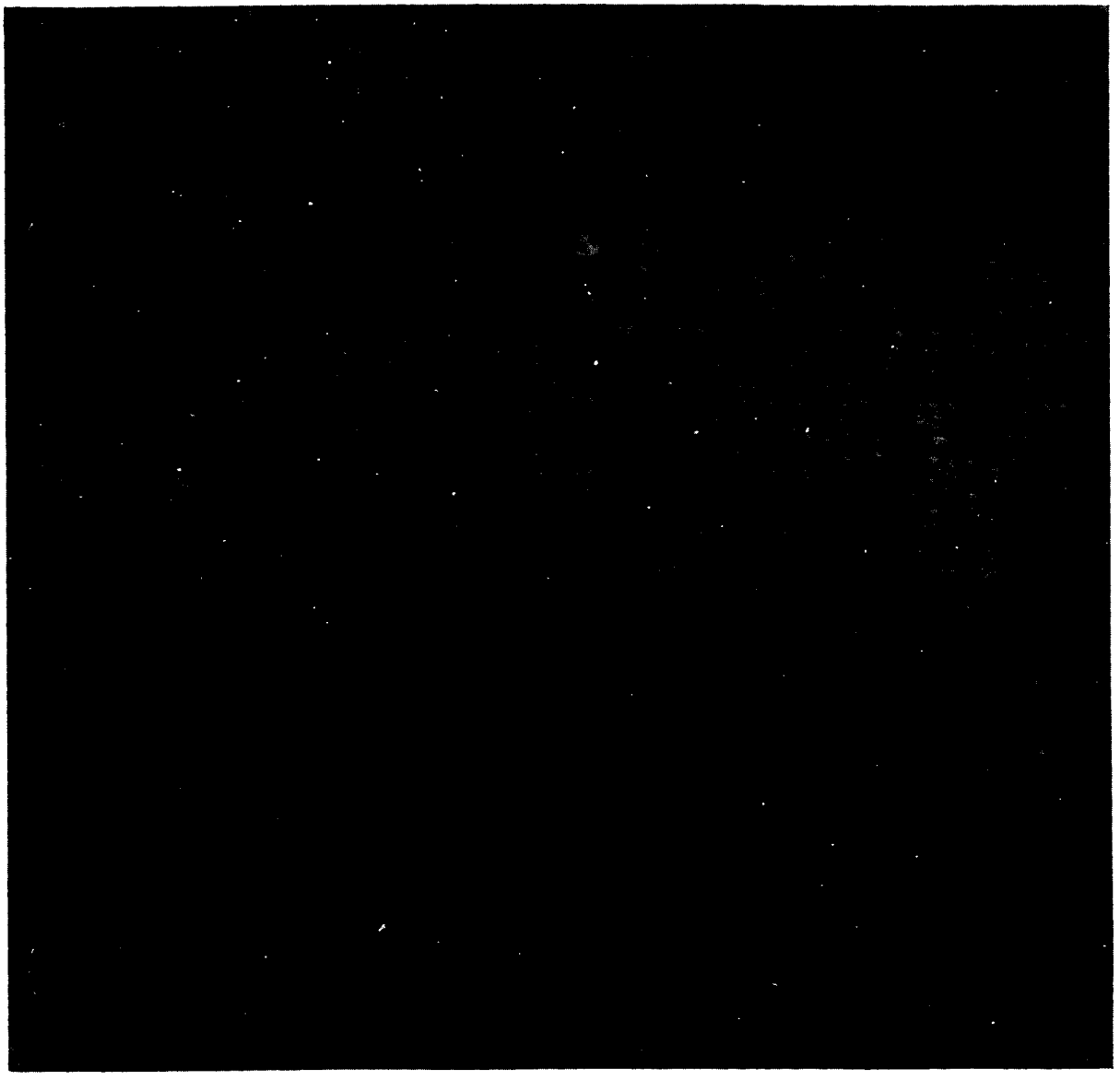
Grating Data

Number: N.R.L. 43, 10-6-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg. 35 min

Measured Height: 420 A



1μ

Electronmicrograph showing an optically-polished glass substrate coated with a gold film. N.R.L. 43 was ruled in this film; it was deposited in the same run with N.R.L. 44.

Picture Data

Film: N161 #24, 11-13-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

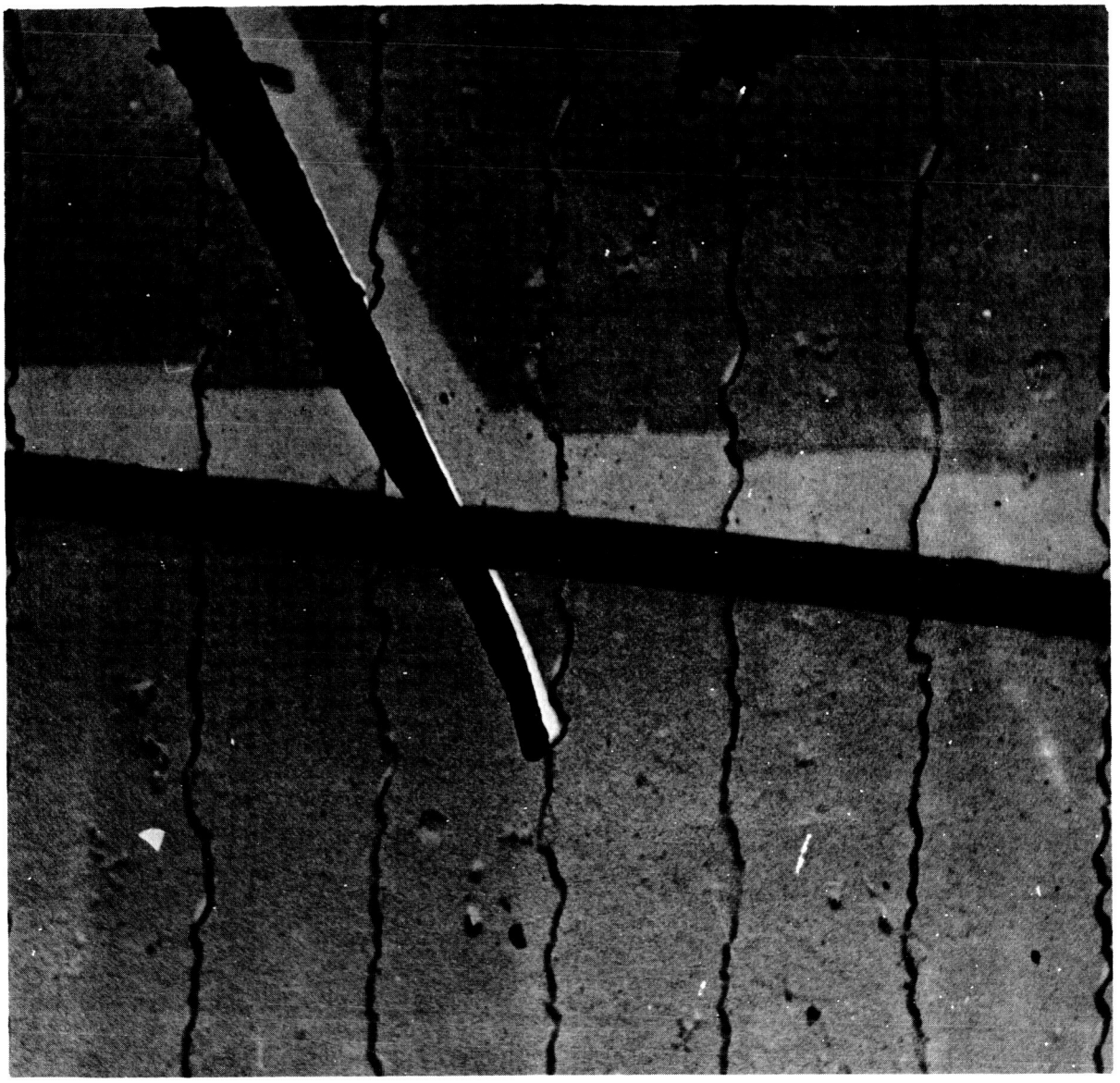
Evaporation Data

Mtl./thick: Au/3200Å

Pressure: 3-5 x 10^{-5} mm

Deposition Rate: 35Å/sec

Coating Method: Electron Gun



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 44.

Picture Data

Film: N152 #18, 10-27-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

Grating Data

Number: N.R.L. 44, 10-8-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Measured Height: 390 A

1μ

Electronmicrograph showing a incompletely-polished glass substrate coated with a gold film. N.R.L. 44 was ruled in this film; it was deposited in the same run with N.R.L. 43.

Picture Data

Film: N161 #30, 11-13-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

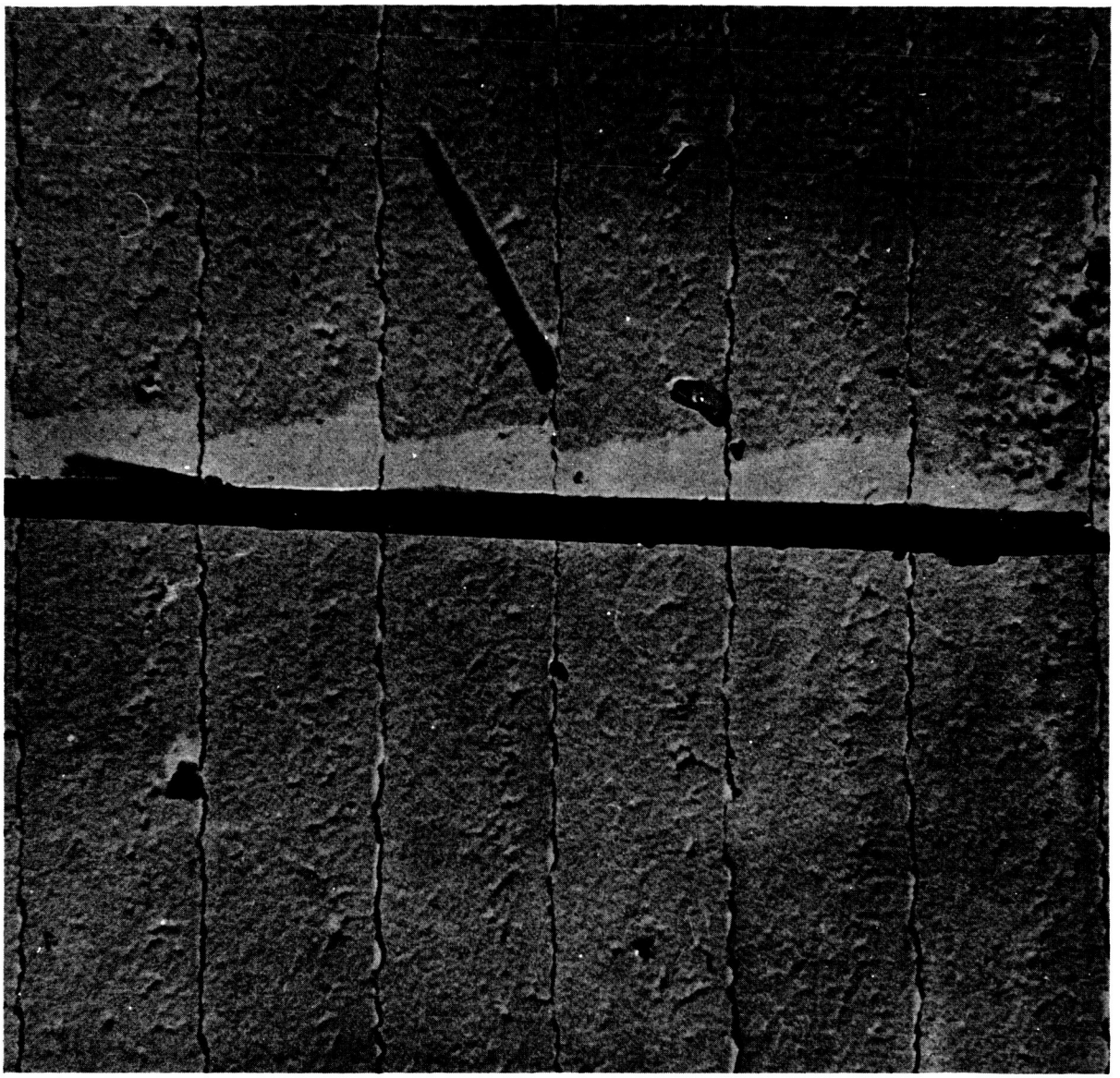
Evaporation Data

Mtl./thick: Au/3200Å

Pressure: 3-5 x 10^{-5} mm

Deposition Rate: 35 Å/sec

Coating Method: Electron Gun



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 45.

Picture Data

Film: N162 #11, 11-14-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

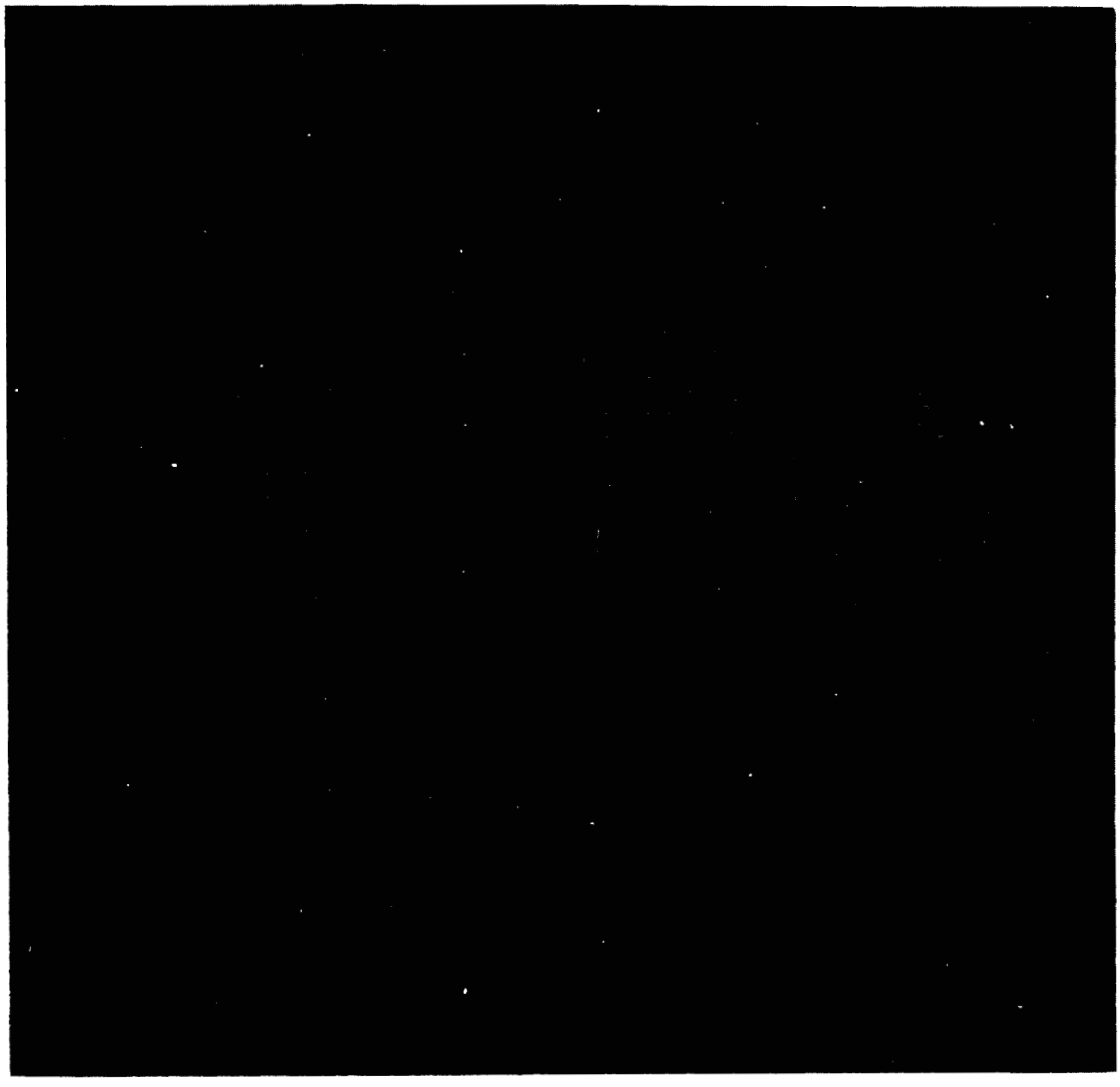
Grating Data

Number: N.R.L. 45, 10-12-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

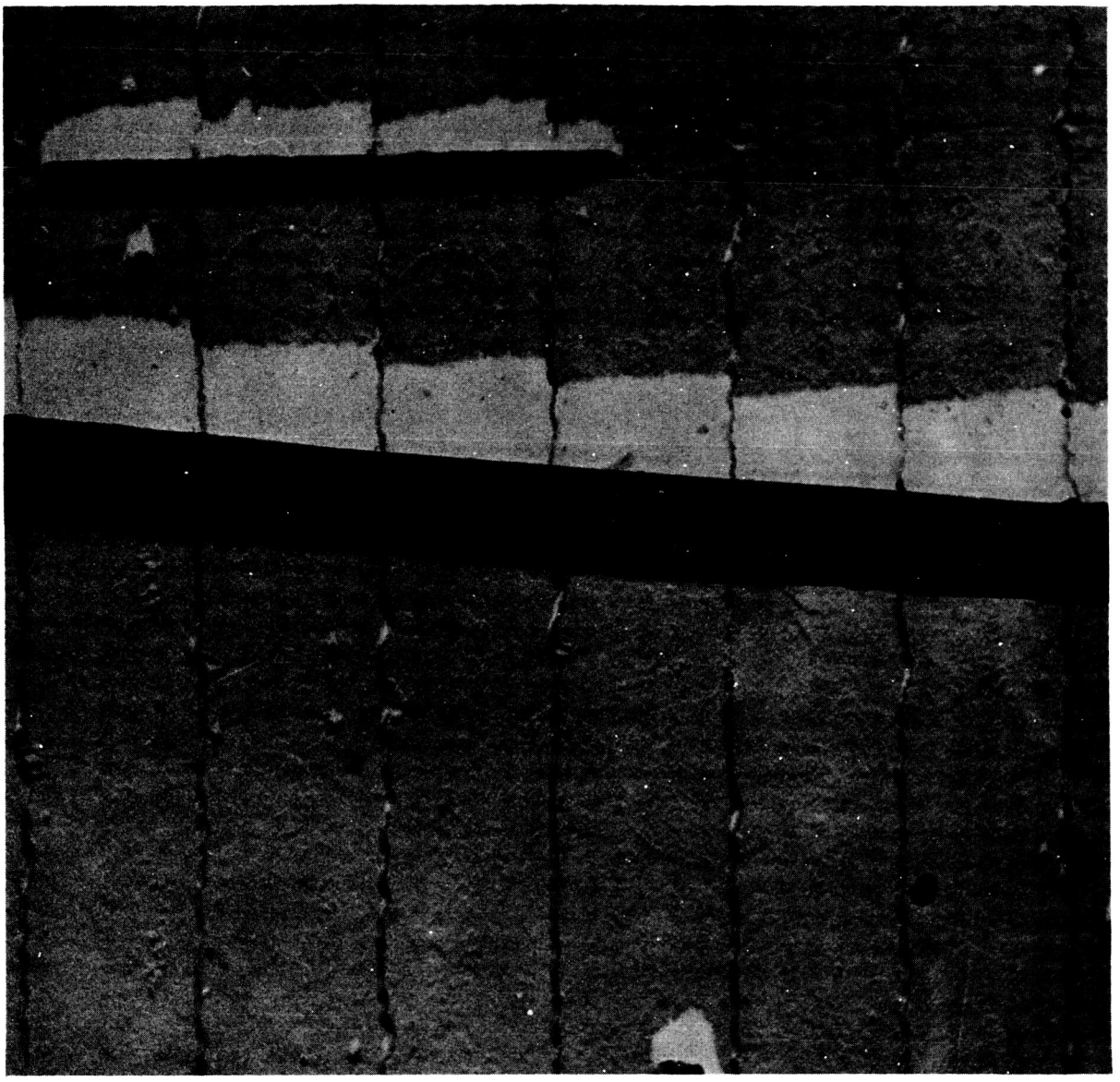
Meas. Height: 470 A
Au-Ge(94%-6%)



1μ

Electronmicrograph showing the gold-germanium (94% - 6%) film in which N.R.L. 45 was ruled.

Picture Data	Evaporation Data
Film: N167 #6, 12-3-64	Mtl./thick: Au-Ge/3000Å
Replica Substrate: Al Film	Pressure: 3-3.5 x 10^{-5} mm
Shadow: Pt-C	Deposition Rate: 18Å/sec.
Specimen Film: C	Coating Method: Electron Gun



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 46.

Picture Data

Film: N164 #18, 11-22-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

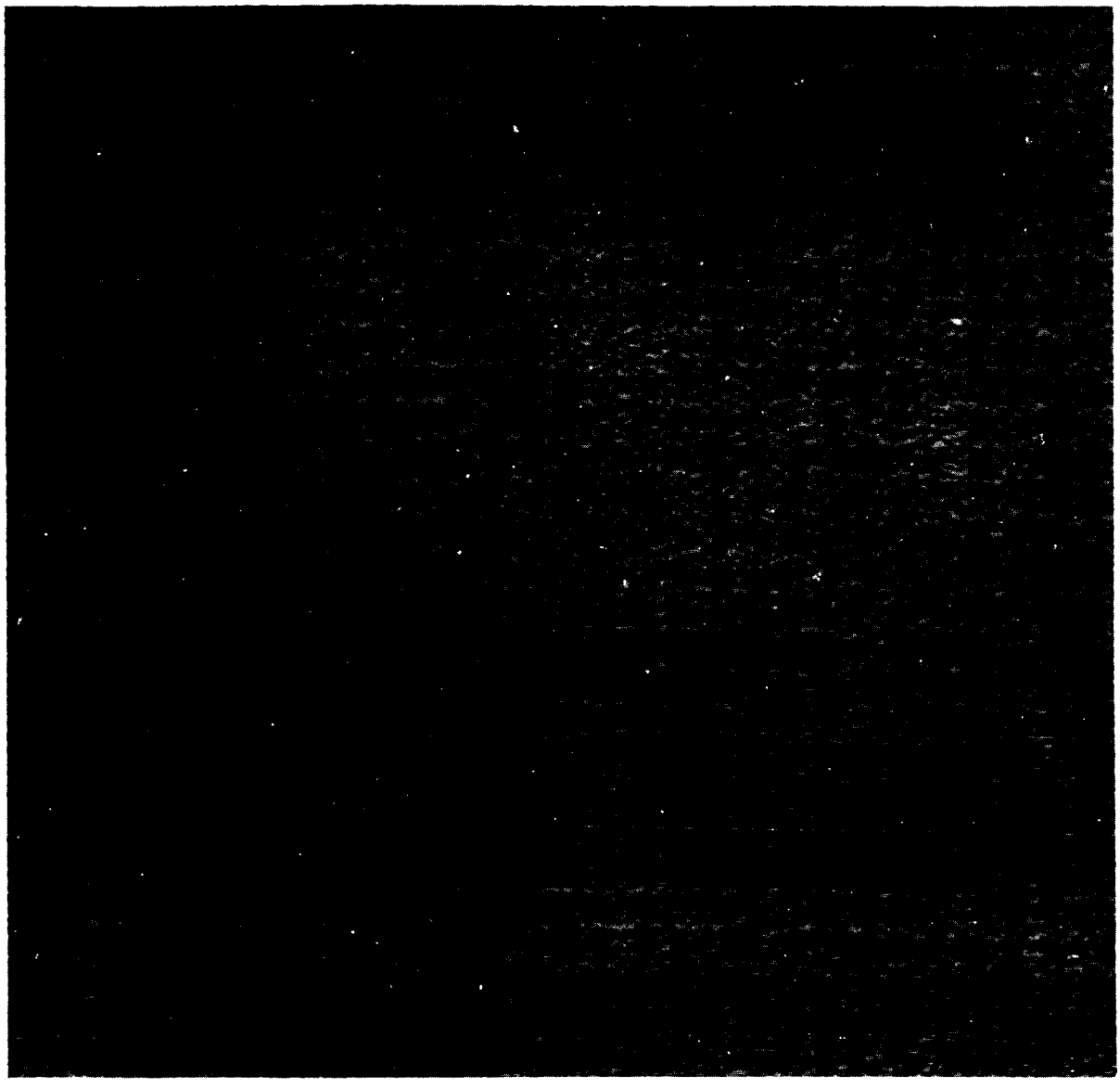
Grating Data

Number: N.R.L. 46, 10-20-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

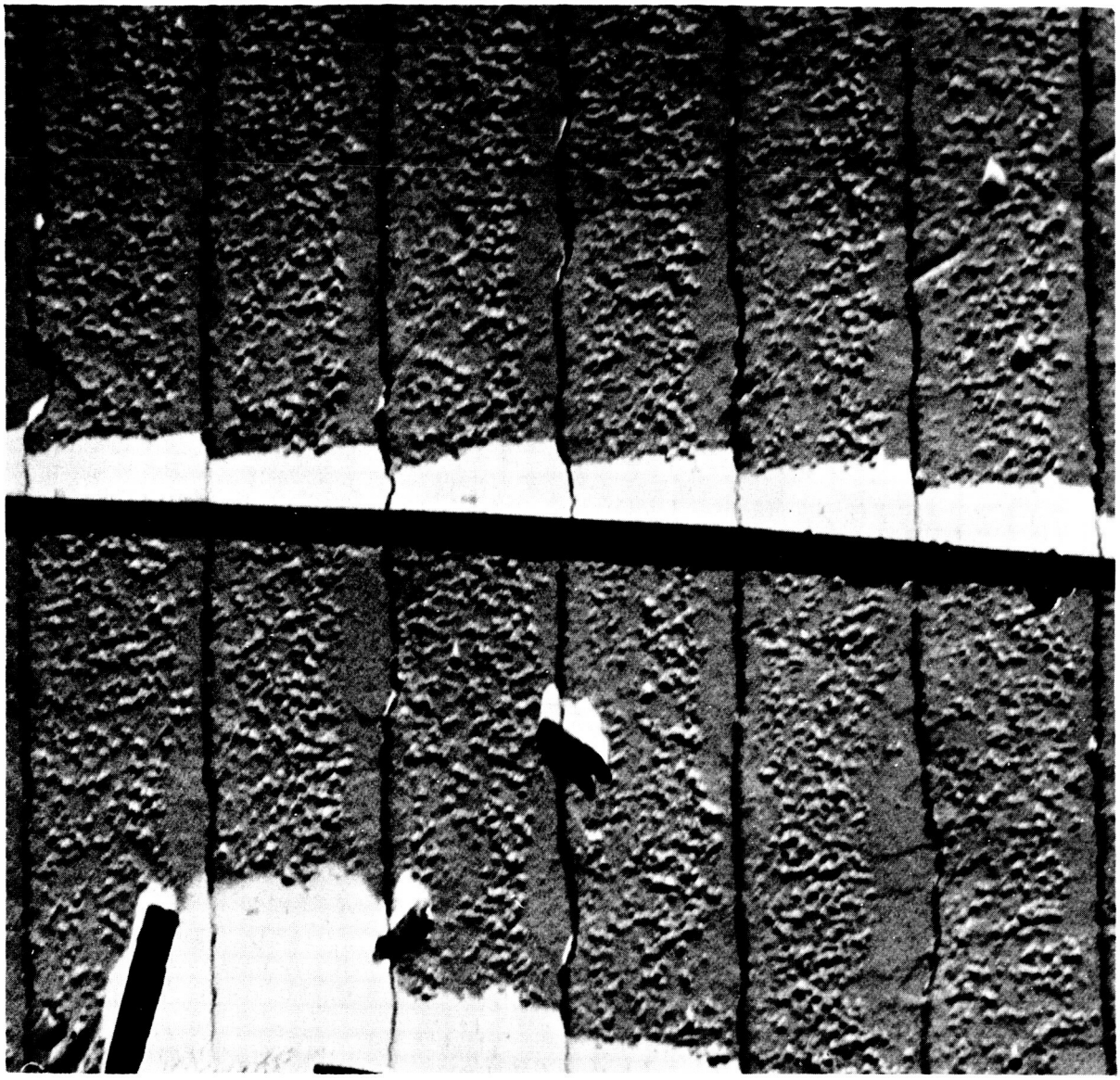
Meas. Height: 400 A



1μ

Electronmicrograph showing an optically-polished glass substrate coated with a gold film. N.R.L. 46 was ruled in this film; the film was deposited in the same run as N.R.L. 47.

Picture Data	Evaporation Data
Film: N167 #8, 12-3-64	Mtl./thick: Au/4000Å
Replica Substrate: Al Film	Pressure: 5×10^{-5} mm
Shadow: Pt-C	Deposition Rate: 45Å/sec
Specimen Film: C	Coating Method: Electron Gun



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 47.

Picture Data

Film: N180 #20, 1-19-65

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

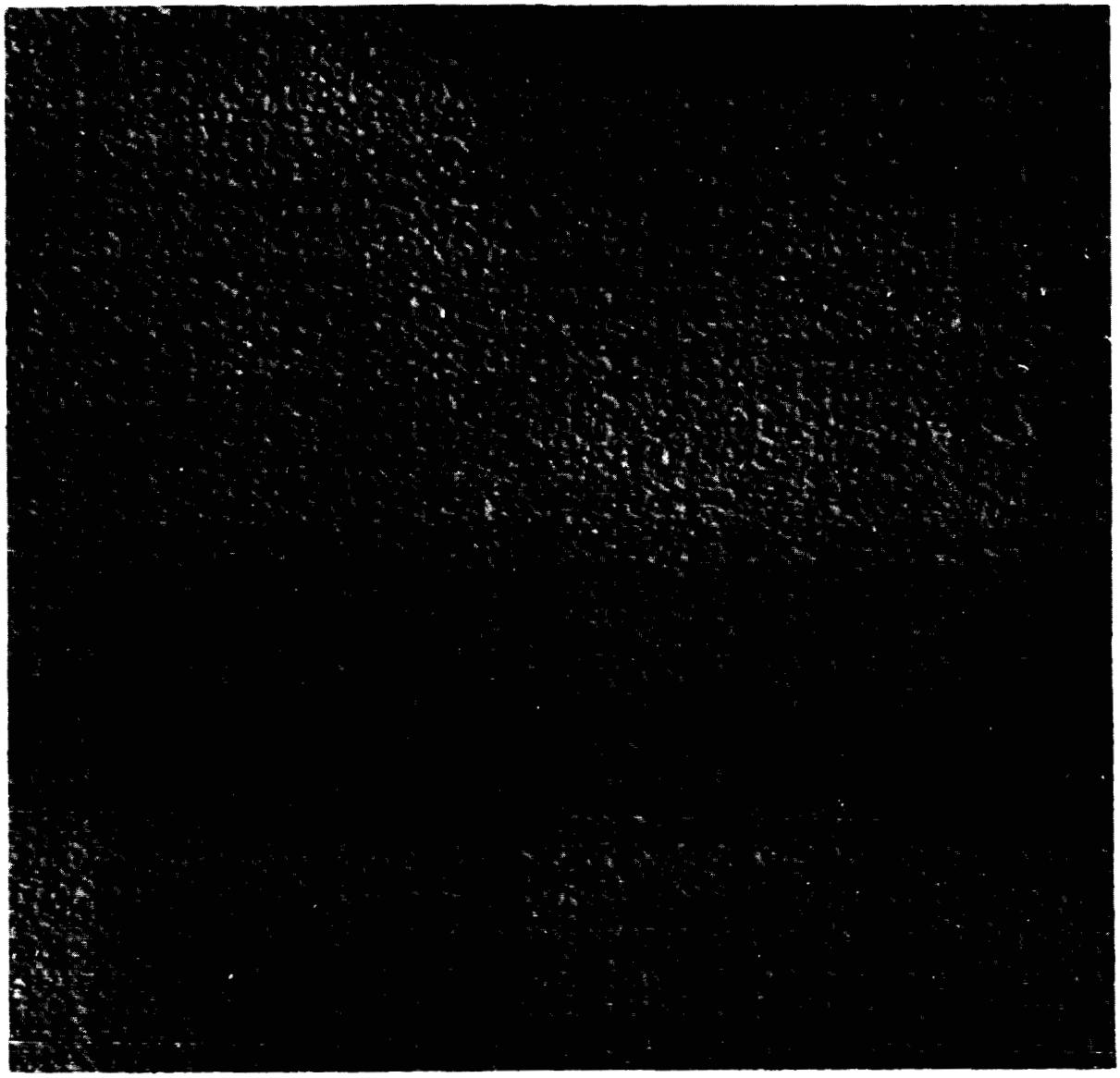
Grating Data

Number: N.R.L. 47, 11-17-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Meas. Height: 450 A



1μ

Electronmicrograph showing a gold coated glass substrate. The substrate was polished at Herron Optical Company by a special underliquid method. N.R.L. 47 was ruled in this film; it was deposited simultaneously with N.R.L. 46.

Picture Data

Film: N167 #15, 11-22-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

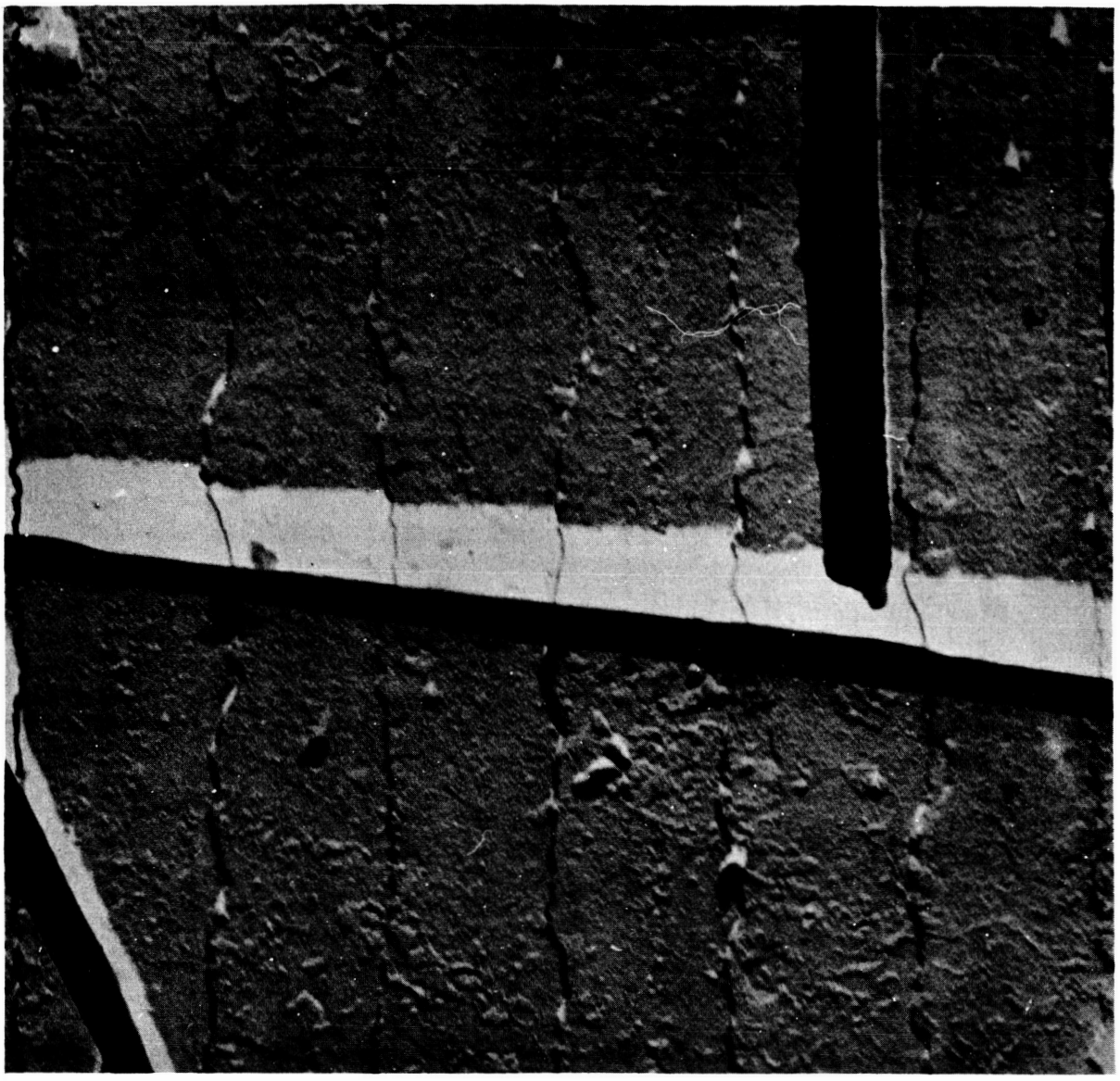
Evaporation Data

Mtl./thick: Au/4000Å

Pressure: 5×10^{-5} mm

Deposition Rate: 45 Å/sec

Coating Method: Electron Gun



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 48.

Picture Data

Film: N180 #10, 1-19-65

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

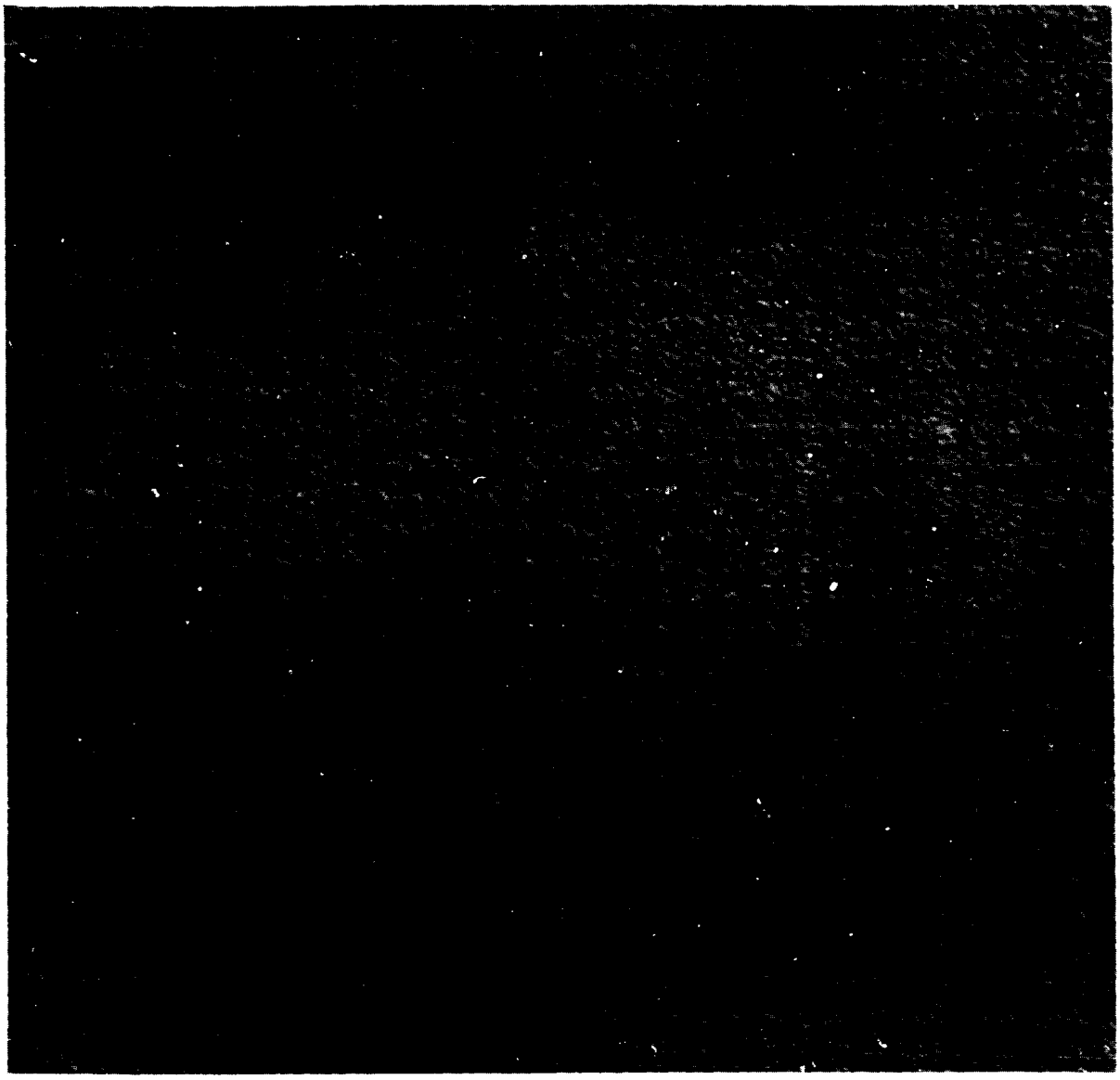
Grating Data

Number: N.R.L. 48, 11-19-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min.

Meas. Height: 420 A



1μ

Electronmicrograph showing the gold film in which N.R.L. 48 was ruled.

Picture Data

Film: N170 #15, 12-7-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

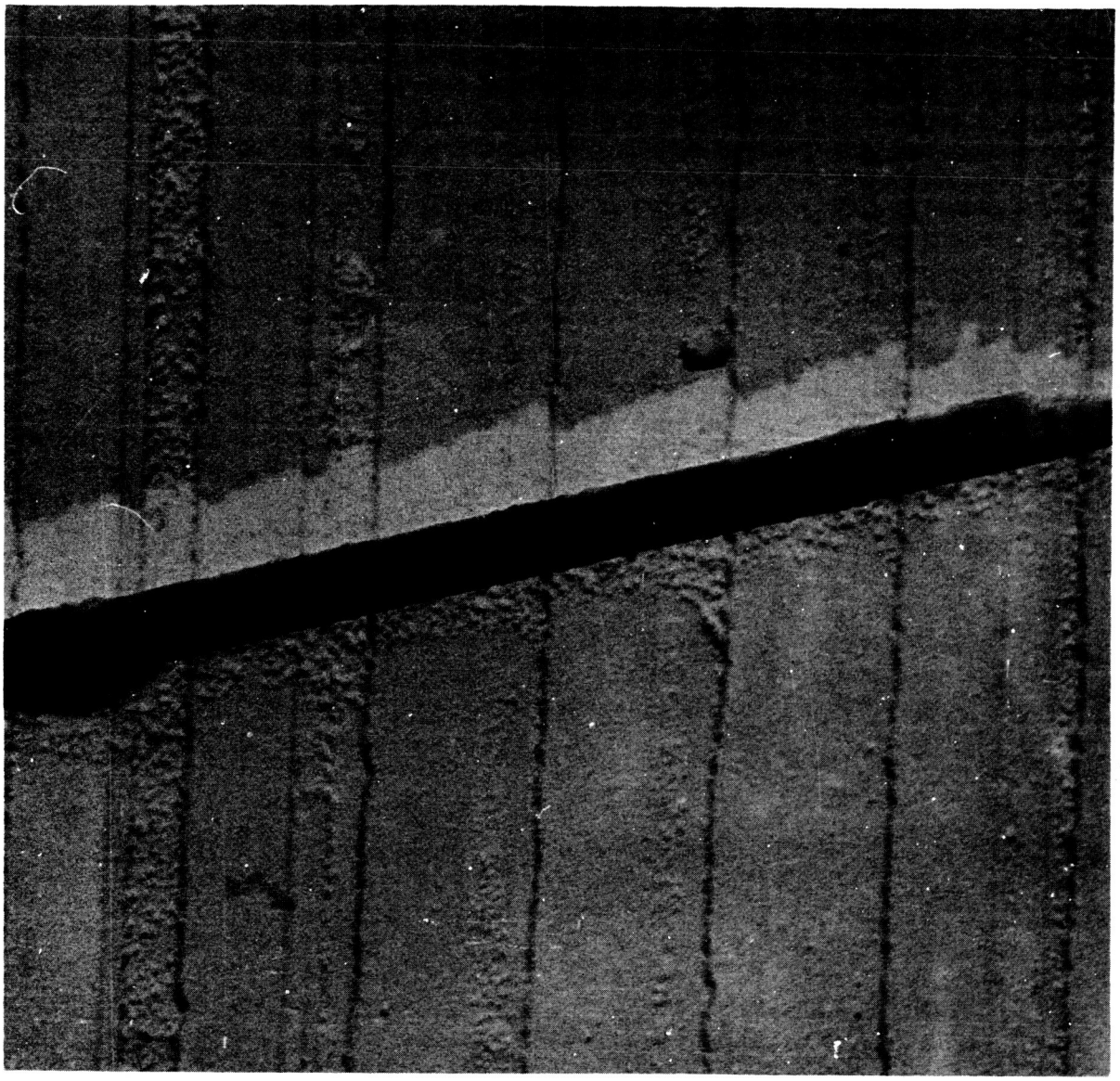
Evaporation Data

Mtl./thick: Au/4400Å

Pressure: 1.2×10^{-5} mm

Deposition Rate: 220 Å/sec

Coating Method: Resistance



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 49.

Picture Data

Film: N166 # 2, 12-1-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

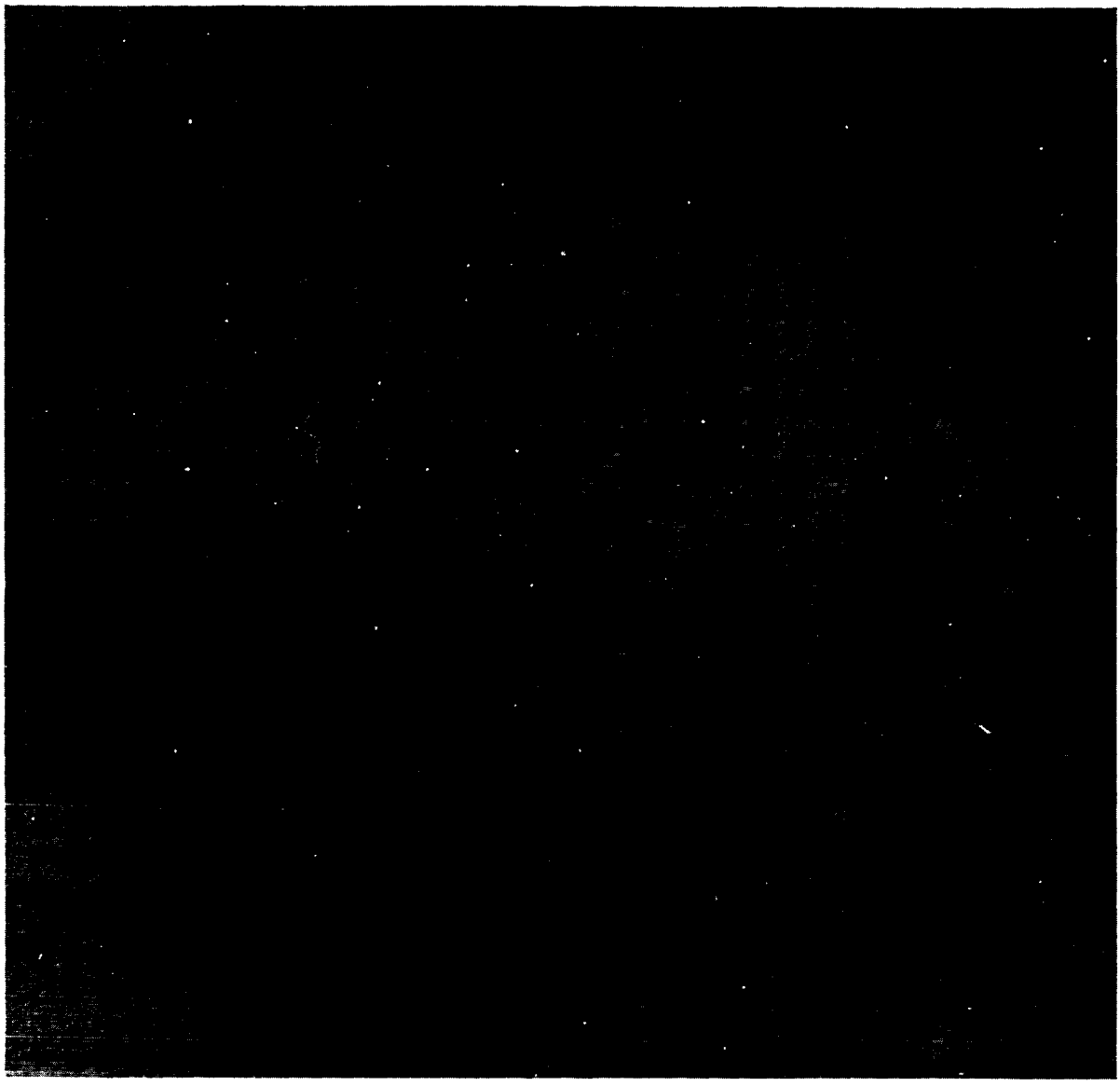
Grating Data

Number: N.R.L. 49, 11-20-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Meas. Height: 430 A



1μ

Electronmicrograph showing the gold film in which N.R.L. 49 was ruled.

Picture Data

Film: N167 #20, 12-3-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

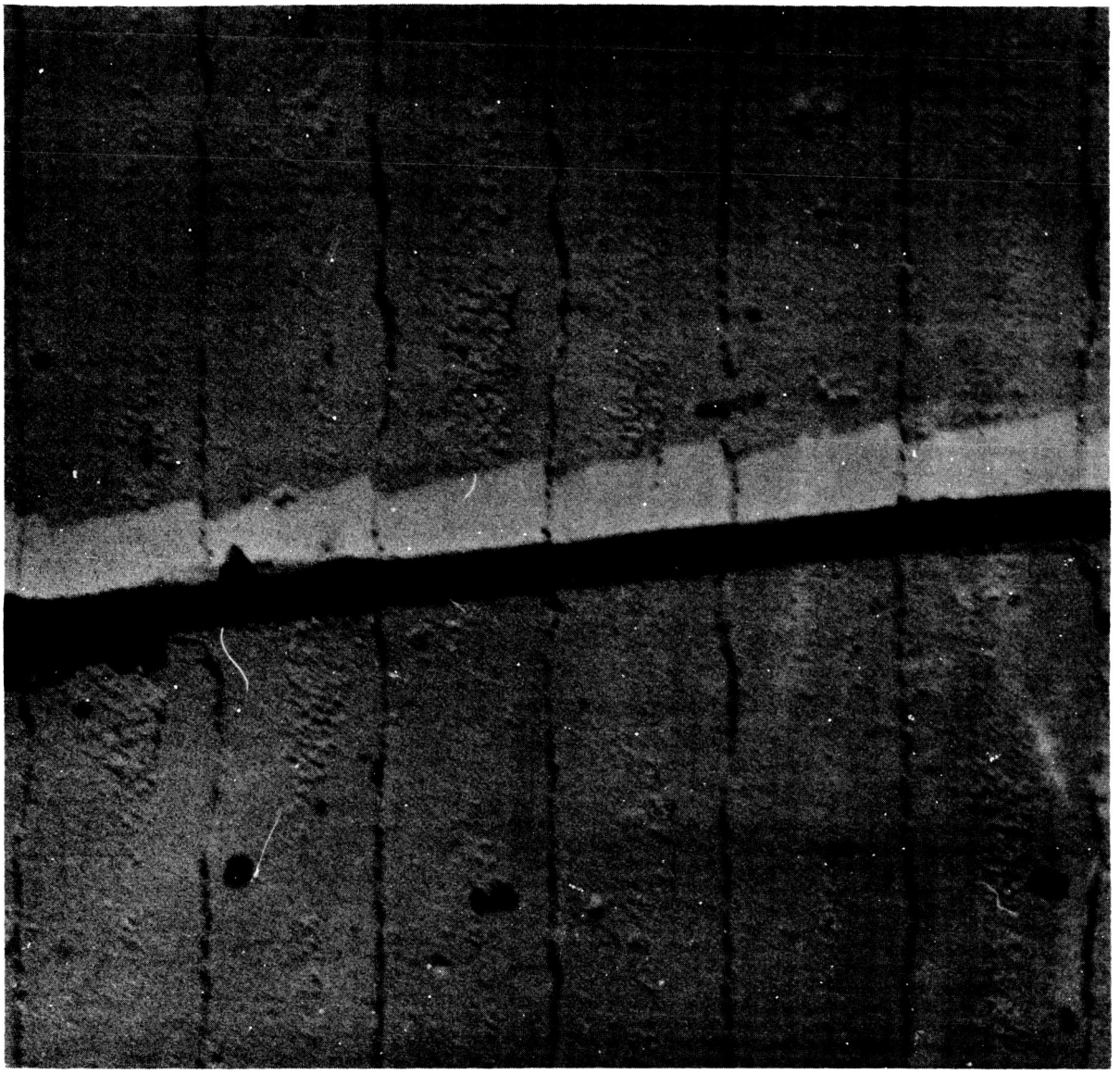
Evaporation Data

Mtl./thick: Au/1300Å

Pressure: 1.1×10^{-5} mm

Deposition Rate: 85 Å/sec

Coating Method: Resistance



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 50.

Picture Data

Film: N166 #18, 12-1-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

Grating Data

Number: N.R.L. 50, 11-22-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Meas. Height: 380 A

1μ

Electronmicrograph showing the gold film in which N.R.L. 50 was ruled.

Picture Data

Film: N167 #29, 12-3-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

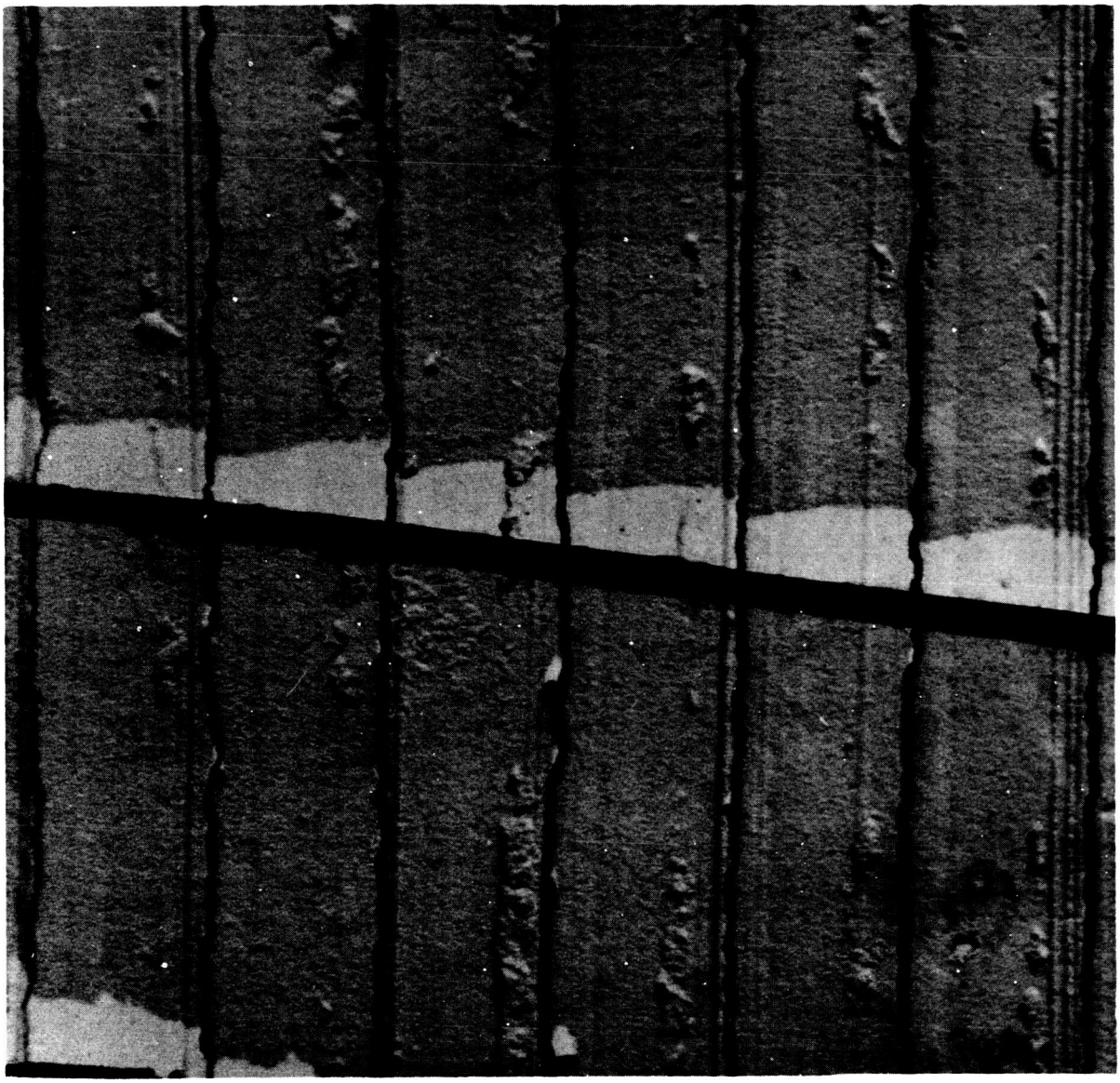
Evaporation Data

Mtl./thick: Au/2700Å

Pressure: 9.5×10^{-6} mm

Deposition Rate: 135 Å/sec

Coating Method: Resistance



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 51.

Picture Data

Film: N181 #18, 1-19-65

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

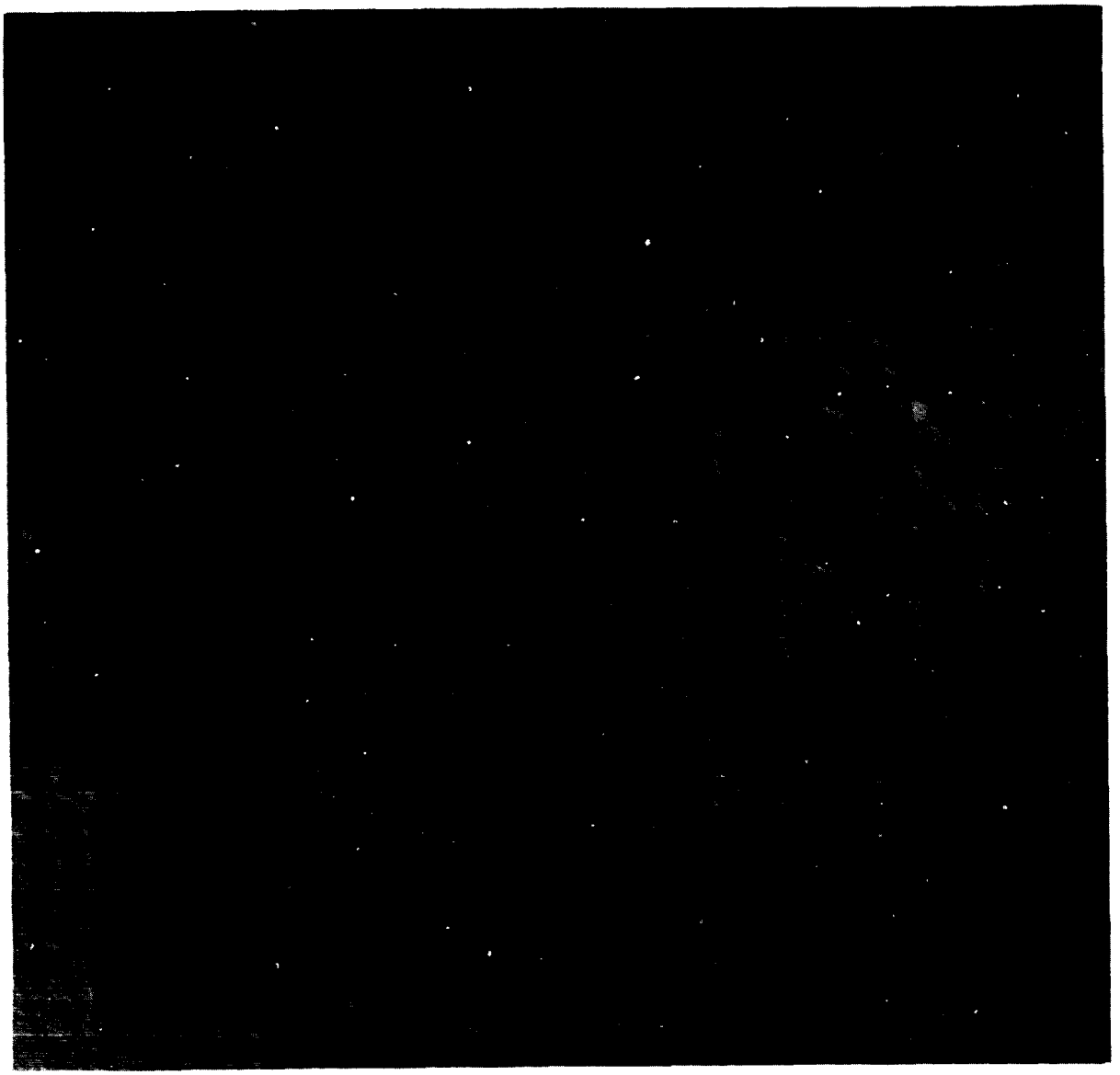
Grating Data

Number: N.R.L. 51, 11-24-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Meas. Height: 520 A



1μ

Electronmicrograph showing the gold film in which N.R.L. 51 was ruled.

Picture Data

Film: N170 #9, 12-7-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

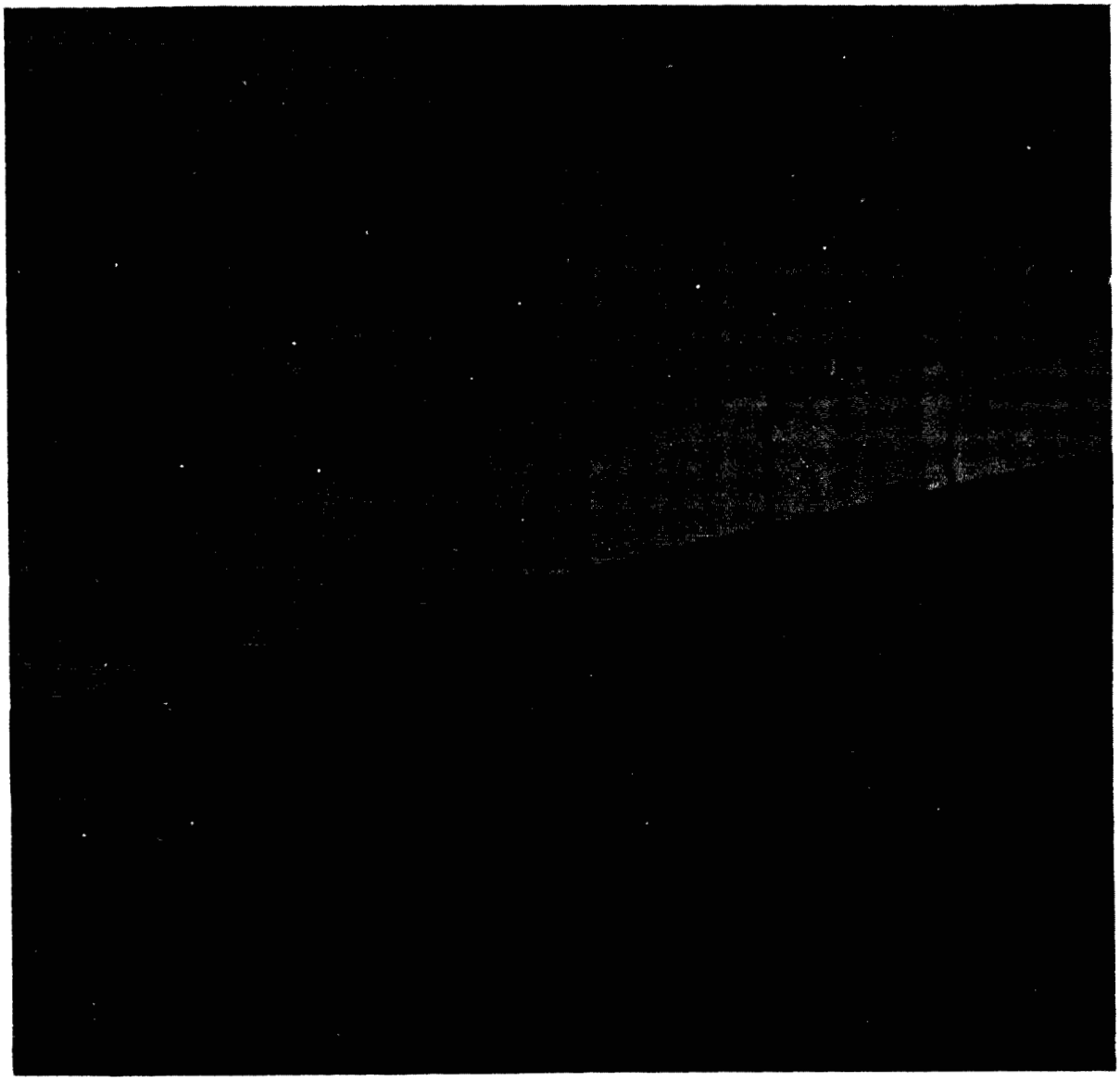
Evaporation Data

Mtl./thick: Au/1600Å

Pressure: 3×10^{-5} mm

Deposition Rate: 16 Å/sec

Coating Method: Resistance



1μ

Electronmicrograph showing grating groove profile in shadow cast by asbestos fiber. N.R.L. test ruling 52.

Picture Data

Film: N170 #23, 12-7-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

Grating Data

Number: N.R.L. 52, 11-25-64

Groove Frequency: 1280 gr./mm

Nominal Slope: 4 deg 35 min

Meas. Height: 540 A

1μ

Electronmicrograph showing the gold film in which N.R.L. 52 was ruled.

Picture Data

Film: N170 #6, 12-7-64

Replica Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

Evaporation Data

Mtl/thick: Au/1600Å

Pressure: 3 x 10-5 mm

Deposition Rate: 16 Å/sec.

Coating Method: Resistance

2. Grating and Film Efficiency Measurements

Three trips to Mr. William Hunter's laboratory at NRL for reflectance and efficiency measurements have been made since the last report was prepared. The tabulated data that follows also includes six gratings previously measured and is therefore complete. This data will be plotted in the Final Report.

The data as tabulated is with respect to a "Standard (10/23/64)" curve that is described in Section 3 of this report. This curve is used to reduce variations attributable to the spectral variation of gold optical constants. The remaining efficiencies are then related to the optical shape and smoothness and diffraction by the grooves.

It is likely that the Standard (10/23/64)" curve will be found rather non-standard by later work. In which case, the original data can be retrieved by multiplying the reduced data by the "Standard" curve, and a new correction could then be applied. Grating NRL 42 measured on 1/13/65 already exceeds the "Standard (10/23/64)" curve at wavelengths between 90 and 103 nanometers. Other difficulties are reported in Section 3.

In the tables that follow, both wavenumber and wavelength units are reported. The spectral intensity distribution by a grating is linear in wavenumber, not wavelength. There is a valid preference to present the data in terms of wavenumber. Nor can one suggest that for small ranges of spectrum it does not matter, because 30 to 200 nanometers is the range here.

Table I. Efficiency measurements of test ruling NRL 4 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
92	61.1	18.1	24.8	108.8
95	64.6	19.4	24.8	105.3
103	64.2	23.6	20.7	97.1
112	63.6	26.6	17.5	89.3
116	67.7	29.8	16.8	86.2
122	66.3	31.4	14.8	82.0

Note: The 2nd Order was observed throughout the efficiency measurements and reached a high of 5.9% at 92 millimicrons.

Table II. Efficiency measurements of test ruling NRL 6 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
92	61.1	23.5	22.8	108.8
95	67.7	26.3	23.3	105.3
103	62.1	27.9	18.6	97.1
104	59.9	28.2	17.6	96.2
112	61.7	30.5	15.6	89.3
116	62.8	33.5	14.9	86.2
122	61.5	34.3	13.6	82.0

Note: The 2nd Order was observed throughout the efficiency measurements and reached a high of 6.0% at 92 millimicrons.

Table III. Efficiency measurements of test ruling NRL 7 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
92	37.6	14.8	22.8	108.8
95	42.1	17.3	24.8	105.3
103	40.7	19.3	20.0	97.1
106	41.7	20.8	18.8	94.3
112	42.2	22.8	16.2	89.3
116	46.0	25.5	16.1	86.2
122	45.0	26.0	13.6	82.0

Note: The 2nd Order was observed throughout the efficiency measurements and reached a peak of 6.0% at 95 millimicrons.

Table IV. Efficiency measurements of test ruling NRL 13 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
70	14.6	2.7	20.5	143.0
74	18.2	2.5	22.6	135.2
80	25.8	5.5	20.9	125.0
83	24.7	4.0	25.3	120.5
85	16.8	4.4	14.8	117.7
92	34.2	9.4	22.8	108.8
95	42.1	11.3	28.6	105.3
103	40.7	13.6	22.9	97.1
112	43.5	18.2	20.1	89.3
113	44.4	21.2	13.7	88.5
116	47.8	15.5	22.6	86.2
122	23.7	11.2	9.5	82.0

Note: The 2nd Order was observed throughout the efficiency measurements and reached a peak of 11.3% at 95 millimicrons.

Table V. Efficiency measurements of test ruling NRL 14 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
70	7.9	1.3	18.5	143.0
75	11.2	1.6	23.8	133.3
80	11.6	2.5	9.2	125.0
83	14.7	2.0	10.7	120.5
85	6.0	0	19.5	117.7
92	20.1	4.0	34.2	108.8
95	24.1	4.5	36.8	105.3
103	25.7	6.4	34.3	97.1
112	29.2	9.7	27.3	89.3
113	33.6	13.0	34.9	88.5
116	32.9	13.0	26.1	86.2
122	34.3	13.6	29.6	82.0
124	36.6	15.7	24.4	80.7

Note: The 2nd Order was observed at 113, 122 and 124 millimicrons, with a peak of 26.6% at 122 millimicrons.

Table VI. Efficiency measurements of test ruling NRL 15 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
122	49.1	8.3	32.0	82.0
124	57.0	7.0	35.5	80.7
128	49.5	7.4	37.0	78.2
133	44.0	6.0	41.2	75.2
137	61.7	7.0	45.4	73.0
144	63.1	6.2	49.7	69.4
149	65.2	5.1	50.8	67.1
157	68.6	5.5	52.2	63.7
161	66.9	4.8	57.3	62.1

Note: The 2nd Order was observed at 122, 124 and 128 millimicrons, with a peak of 7.6% at 124 millimicrons.

Table VII. Efficiency measurements of test ruling NRL 16 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
135	28.1	1.6	37.3	74.1
140	29.5	1.0	40.5	71.4
144	28.2	0.0	40.5	69.4
146	29.4	1.0	42.6	68.5
149	29.2	0.0	43.7	67.1
152	32.8	0.0	48.2	65.8
158	35.8	0.0	51.8	63.3
161	37.2	0.0	51.8	62.1
173	20.5	1.0	32.6	57.8
178	16.6	1.0	27.5	56.2
185	14.4	1.5	24.3	54.1
191	14.6	0.9	18.4	52.4
196	14.2	1.4	16.5	51.0

Table VIII. Efficiency measurements of test ruling NRL 17 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
157	35.3	0	55.7	63.7
161	35.2	0	54.8	62.1
174	40.1	0	60.4	57.4
180	38.5	0	52.8	55.6
185	37.6	0	51.5	54.1
192	41.3	0	52.2	52.1
195	41.7	0	51.0	51.3
200	42.1	0	49.6	50.0

Table IX. Efficiency measurements of test ruling NRL 19 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
122	35.5	5.3	28.4	82.0
128	36.4	7.4	27.3	78.1
135	38.1	2.7	26.1	74.1
144	40.0	8.7	25.2	69.4
149	42.7	9.5	24.1	67.1
152	44.7	9.9	25.8	65.8
158	49.8	12.9	27.8	63.3
161	48.2	13.1	26.7	62.1
173	29.5	7.9	10.0	57.8
178	23.3	4.1	13.0	56.2

Note: The 2nd Order was observed throughout the efficiency measurements and reached a peak of 5.0% at 158 millimicrons.

Table X. Efficiency measurements of test ruling NRL 20 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
83	69.4	0.0	68.7	120.5
92	70.4	0.0	66.5	108.8
95	79.0	0.0	75.2	105.3
103	67.8	3.6	57.2	97.1
116	69.0	9.3	47.2	86.2
122	68.6	11.8	47.3	82.0

Note: The 2nd Order was observed at 116 and 122 millimicrons with a relative efficiency of 3.0%.

Table XI. Efficiency measurements of test ruling NRL 21 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	2nd Order	Wavenumber in Kilokaysers
30	100.0	No data	No data	333.3
55	69.0	No data	No data	182.0
92	98.0	3.4	55.7	108.8
103	92.1	78.6	45.0	97.1
108	88.0	6.8	50.7	92.6
118	86.2	7.8	48.2	89.8
124	96.5	9.3	56.9	80.7
137	81.1	50.3	33.5	73.0

Note: 2nd Order relative efficiency is given in this table. No 1st Order data was visible except at 137 millimicrons which had a relative efficiency of 8.6%.

Comment: The valves at 103 millimicrons are not high because of numerical errors and they were rechecked on different gain scales at the time of measurement.

Table XII. Efficiency measurements of test ruling NRL 22 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
50	36.1	3.6	57.3	200.0
55	21.4	6.9	26.8	182.0
63	28.6	5.7	40.3	158.8
69	43.5	6.5	60.3	145.0
76	40.7	4.3	69.2	131.7
78	41.1	1.8	69.3	128.2
80	45.4	1.8	71.2	125.0
83	47.3	0.0	79.3	120.5
92	51.0	3.4	75.2	108.8
95	56.0	3.7	74.6	105.2
103	53.8	3.6	64.3	97.1
116	49.4	6.2	52.5	86.2
122	48.0	5.9	50.8	82.0

Note: The 2nd Order was observed from 80 millimicrons through 50 millimicrons and peaking at 55 millimicrons with a relative efficiency of 33.8%.

Table XIII. Efficiency measurements of test ruling NRL 23 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
32	100.0	17.9	8.9	313.0
38	100.0	21.1	21.0	263.5
45	100.0	No data	No data	222.0
51	100.0	20.1	0.6	196.0
55	100.0	11.4	1.4	182.0
63	100.0	6.1	12.2	158.8
69	100.0	1.9	24.7	145.0
70	100.0	2.0	25.8	143.0
76	100.0	1.2	37.7	131.6
80	100.0	1.2	44.8	125.0
83	100.0	1.3	51.3	120.5
90	100.0	1.3	55.9	111.2
92	99.4	0.0	51.7	108.8
95	91.7	3.0	57.1	105.2
104	85.7	3.6	64.3	96.2
112	75.3	6.5	49.4	89.3
116	77.2	6.2	49.4	86.2
122	78.7	6.5	50.8	82.0
134	76.7	10.9	44.0	74.7
137	78.5	13.4	43.6	73.0

Note: (1) The 2nd Order was observed throughout almost the entire spectral range with a peak relative efficiency of 23.8% at 55 millimicrons.

(2) The 3rd Order was observed from 51 through 90 millimicrons with a peak relative efficiency of 22.1% at 69 millimicrons.

Table XIV. Efficiency measurements of test ruling NRL 24 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
32	0.0	0.0	0.0	313.0
45	53.5	22.8	75.0	222.0
55	3.5	8.6	50.3	182.0
61	4.5	8.5	46.9	164.0
63	7.4	14.7	63.2	158.8
68	13.4	13.4	68.8	147.0
76	9.3	13.0	72.9	131.6
83	10.7	10.7	69.4	120.5
93	19.6	18.9	69.6	107.5
103	22.1	15.0	55.0	97.1

Note: The 2nd Order was observed throughout the entire spectral range with a peak relative efficiency of 14.7% at 63 millimicrons.

Table XV. Efficiency measurements of test ruling NRL 25 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
45	81.2	10.6	25.9	222.0
51	78.7	0.0	28.4	196.0
55	69.7	0.0	31.4	182.0
61	67.2	0.0	40.5	164.0
63	67.5	0.0	42.8	158.8
69	73.4	0.0	51.9	145.0
70	78.2	0.0	57.6	143.0
76	76.0	0.0	55.6	131.6
79	81.0	0.0	50.9	126.7
83	93.3	1.3	62.0	120.5
92	100.0	6.7	65.1	108.8
96	100.0	7.5	61.6	104.3
103	100.0	11.4	53.6	97.1
109	88.4	12.2	43.6	91.8
119	86.7	16.9	40.4	84.0
124	90.1	22.1	54.1	80.7
137	88.1	25.4	8.1	73.0

Note: (1) The 2nd Order was observed throughout the entire spectral range with a peak relative efficiency of 18.0% at 51 millimicrons and 30.3% at 137 millimicrons.

(2) The 3rd Order was observed between 51 and 61 millimicrons and the 4th Order was observed at 55 millimicrons.

Table XVI. Efficiency measurements of test ruling NRL 26 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
45	81.2	11.8	31.8	222.0
51	78.7	2.4	23.7	196.0
55	69.7	1.1	24.2	182.0
61	67.2	0.8	31.0	164.0
63	67.5	0.9	30.9	158.8
69	73.4	0.6	46.8	145.0
70	78.2	0.0	52.3	143.0
76	76.0	0.0	55.5	131.6
79	81.0	11.0	50.9	126.7
83	93.3	3.3	65.9	120.5
92	100.0	6.7	71.8	108.8
96	100.0	6.0	65.4	104.3
103	100.0	11.4	60.0	97.1
109	88.4	14.3	52.1	91.8
119	86.7	19.9	43.4	84.0
124	90.1	23.8	59.9	80.7
137	88.1	23.8	5.4	73.0

Note: (1) The 2nd Order was observed throughout almost the entire spectral range with a peak relative efficiency of 26.6% at 51 millimicrons.

(2) The 3rd Order was observed from 51 through 63 millimicrons and the 4th. Order was observed at 55 millimicrons.

Table XVII. Efficiency measurements of test ruling NRL 28 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st. Order	Wavenumber in Kilokaysers
45	98.9	5.9	25.9	222.0
51	74.6	7.1	30.2	196.0
55	71.7	8.6	36.6	182.0
61	63.6	8.5	38.9	164.0
69	74.0	9.7	48.7	145.0
76	74.7	8.0	48.2	131.6
83	86.0	10.0	52.7	120.5
92	92.7	12.1	54.4	108.8
96	93.2	13.5	56.4	104.3
103	92.9	19.3	47.9	97.1
117	82.8	23.9	33.8	85.5
122	86.4	25.4	31.4	82.0
137	82.7	28.1	10.8	73.0

Note: (1) The 2nd Order was observed throughout the entire spectral ranges with high relative efficiencies of 15.3% at 45 millimicrons and 22.2% at 137 millimicrons.

(2) The 3rd Order was observed from 45 through 61 millimicrons and the 4th Order was observed from 45 through 51 millimicrons and at 137 millimicrons.

Table XVIII. Efficiency measurements of test ruling NRL 29 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
45	98.9	77.7	8.2	222.0
51	74.6	45.6	11.2	196.0
55	71.7	18.6	15.2	182.0
61	63.6	39.3	17.4	164.0
69	74.0	53.2	24.7	145.0
76	74.7	53.7	25.3	131.6
83	86.0	62.7	26.0	120.5
92	92.7	65.1	28.2	108.8
96	93.2	80.5	26.3	104.3
103	92.9	74.3	23.6	97.1
117	82.8	63.8	19.0	85.5
122	86.4	61.6	19.5	82.0
137	82.7	79.4	No data	73.0

Note: (1) The 2nd Order was observed throughout the entire spectral range with a peak relative efficiency of 13.6% at 122 millimicrons.

(2) The 1st Order was observed from 45 through 61 millimicrons.

(3) The 3rd, 4th, and 5th Orders were observed at 51 and 55 millimicrons.

Table XIX. Efficiency measurements of test ruling NRL 30 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
30	21.3	4.3	0.0	333.3
46	27.0	13.0	0.0	217.5
51	29.1	9.3	1.7	196.0
55	30.7	21.7	1.7	182.0
61	34.0	22.3	2.8	164.0
69	43.5	37.0	2.6	145.0
76	47.5	34.0	2.5	131.6
83	57.3	32.7	2.7	120.5
92	67.8	43.0	2.0	108.8
103	58.5	40.7	1.4	97.1
119	55.4	32.0	0.6	84.0

Table XX. Efficiency measurements of test ruling NRL 31 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
30	46.8	0.0	34.1	333.3
45	29.4	0.0	17.7	222.0
51	18.2	0.0	30.8	196.0
55	17.9	0.0	29.7	182.0
62	23.0	0.0	33.8	161.3
70	31.1	0.7	42.4	143.0
76	34.6	1.9	46.9	131.6
79	36.8	3.1	46.6	126.7
83	44.0	3.3	46.0	120.5
90	44.0	8.8	44.1	111.2
96	51.9	8.3	45.9	104.3
101	49.6	13.1	41.6	99.0
104	54.3	14.3	43.6	96.2
108	49.0	14.3	36.8	92.6
118	50.6	19.3	31.3	84.8
124	52.9	21.5	28.5	80.7

Note: The 2nd Order was observed from 79 through 124 millimicrons with a peak relative efficiency of 4.2% at 118 millimicrons.

Table XXI. Efficiency measurements of test ruling NRL 32 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies %			Wavenumber in Kilokaysers
	Unruled Area	0th. Order	1st Order	
30	4.2	0	0	333.3
37	4.0	0	0	268.0
42	25.0	0	0	239.2
48	17.5	0	0	209.0
53	15.4	1.9	6.0	190.0
55	16.6	0.7	6.9	181.0
61	19.8	1.2	8.9	164.3
68	27.3	0	16.9	146.3
75	29.4	1.2	20.0	133.7
83	47.3	3.3	24.0	120.0
90	45.9	5.0	20.1	111.2
92	55.2	7.7	23.1	108.8
95	54.9	11.3	26.3	105.3
98	60.9	12.0	24.8	102.4
103	57.8	15.0	24.3	97.1
107	56.2	14.6	22.2	93.8
112	58.5	18.8	22.1	89.3
117	59.4	21.2	18.2	85.1
122	57.0	21.8	16.5	82.0

Note: The 2nd Order was observed from 75 millimicrons through 122 millimicrons with a peak relative efficiency of 9.0% at 98 and 112 millimicrons.

Table XXII. Efficiency measurements of test ruling NRL 33 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies %			Wavenumber in Kilokaysers
	Unruled Area	0th. Order	1st Order	
83	78.0	7.3	40.0	120.0
90	71.1	6.3	35.2	111.2
95	81.6	7.5	47.7	105.3
101	74.1	7.2	40.3	99.0
103	72.8	6.4	40.7	97.1
110	69.4	6.7	36.7	90.7
115	68.2	7.5	36.9	87.3
122	65.9	8.8	35.3	82.0
125	68.8	8.1	41.6	79.8
134	70.1	14.7	32.6	74.4
140	71.0	17.4	33.7	71.5
146	73.6	18.3	31.5	68.3
152	77.4	24.0	29.0	65.9
161	80.9	26.6	29.2	62.2

Note: The 2nd Order was observed throughout the efficiency measurements and reached a high (relative efficiency) of 12.0% at 83 millimicrons.

Table XXIII. Efficiency measurements of test ruling NRL 34 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
83	78.0	2.0	30.7	120.0
90	71.1	1.3	32.1	111.2
95	81.6	3.0	45.1	105.3
101	74.1	1.4	39.6	99.0
103	72.8	0.7	42.2	97.1
110	69.4	1.3	36.0	90.7
115	68.2	1.2	37.5	87.3
122	65.9	0.6	36.5	82.0
125	68.8	1.7	34.7	79.8
134	70.1	4.6	32.6	74.4
140	71.0	4.9	33.7	71.7
146	73.6	6.6	34.6	68.3
152	77.4	6.7	39.0	65.9
161	80.9	12.1	36.2	62.2

Note: The 2nd Order was observed from 83 millimicrons through 125 millimicrons and reached a high (relative efficiency) of 7.3% at 83 millimicrons.

Table XXIV. Efficiency measurements of test ruling NRL 35 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
30	21.3	2.1	8.5	333.3
55	22.1	1.4	37.6	181.0
63	23.5	-	40.9	159.3
70	36.0	-	54.6	142.8
76	36.4	-	50.0	131.7
79	40.8	-	58.5	127.1
83	49.7	-	63.5	120.0
92	59.0	2.9	59.0	108.8
102	65.0	9.3	53.6	97.1

Note: The 2nd Order was visible at 30 and 55 millimicrons and reached a high (relative efficiency) of 51.0% at 30 millimicrons.

Table XXV. Efficiency measurements of test ruling NRL 36 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
101	57.6	3.6	27.4	99.0
105	56.3	1.4	29.6	95.4
110	58.0	0.7	32.7	90.7
114	63.2	1.2	28.1	87.3
122	65.9	2.9	28.8	82.0
125	67.1	11.5	27.8	79.8
128	62.5	9.7	28.4	78.4
134	63.1	11.4	26.1	74.4
140	72.7	16.8	30.0	71.5
146	73.6	20.3	30.0	68.3

Note: The 2nd Order was observed throughout the spectral range with a peak relative efficiency of 1.7% at 125 millimicrons.

Table XXVI. Efficiency measurements of test ruling NRL 37 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
55	23.8	0	22.4	181.0
58	26.3	0.4	27.0	171.0
63	25.6	1.3	27.8	159.3
70	35.8	1.3	45.0	142.8
76	40.7	1.2	40.8	131.7
79	45.7	1.2	44.5	127.1
83	57.3	4.7	47.3	120.0
92	63.1	5.4	58.4	108.8
95	71.4	8.2	58.8	105.3
100	63.5	8.0	54.0	99.5
105	66.9	11.3	46.5	95.4
112	81.2	16.9	44.2	89.3
118	77.6	19.4	43.0	84.6
122	77.7	20.0	38.2	82.0
123	77.2	21.0	36.3	81.3
128	78.4	25.0	35.8	78.4
135	82.8	29.8	35.2	73.9

Note: The 2nd Order was observed from 55 millimicrons through 70 millimicrons and at 112, 118, and 135 millimicrons. The 2nd Order reached a high (relative efficiency) of 8.3% at 55 millimicrons.

Table XXVII. Efficiency measurements of test ruling NRL 38 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
55	23.8	3.1	23.8	181.0
58	26.3	2.6	25.6	171.0
63	25.6	3.5	25.7	159.3
70	35.8	5.3	33.1	142.8
76	40.7	5.6	32.8	131.7
79	45.7	6.7	33.6	127.1
83	57.3	9.3	42.7	120.0
92	63.1	13.4	40.3	108.8
95	71.4	17.0	45.5	105.3
100	63.5	16.1	16.0	99.5
105	66.9	21.1	32.4	95.4
112	81.2	27.3	33.1	89.3
118	77.6	34.0	29.1	84.6
122	77.7	34.1	25.9	82.0
123	77.2	35.1	24.0	81.3
128	78.4	38.6	23.8	78.4
135	82.8	46.0	22.2	73.9

Note: The 2nd Order was observed from 55 millimicrons through 70 millimicrons and at 112 millimicrons. The 2nd Order reached a high (relative efficiency) of 4.1% at 55 millimicrons.

Table XXVIII. Efficiency measurements of test ruling NRL 39 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th. Order	1st Order	Wavenumber in Kilokaysers
30	36.2	0	0	333.3
34.5	52.3	0	0	290.0
37	56.0	0	0	268.0
42	57.9	0	13.2	239.2
46	63.2	0	24.4	217.5
51	50.9	5.3	36.7	197.0
55	43.5	5.2	32.8	181.0
61	44.5	2.8	24.7	164.3
68	54.6	3.3	31.2	146.3
75	58.1	7.5	33.8	133.7
83	75.3	11.3	39.4	120.0
92	78.5	16.8	39.0	108.8
103	85.0	22.2	31.4	97.1

Note: The 2nd Order was observed from 30 millimicrons through 61 millimicrons and reached a high (relative efficiency) of 46.0% at 42 millimicrons.

Table XXIX. Efficiency measurments of test ruling NRL 40 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th. Order	1st Order	Wavenumber in Kilokaysers
30	36.2	0	0	333.3
34.5	52.3	0	0	290.0
37	56.0	0	0	268.0
42	57.9	0	13.2	239.2
46	63.2	0	16.8	217.5
51	50.9	3.0	20.1	197.0
55	43.5	1.7	22.8	181.0
61	44.5	0	20.3	164.3
68	54.6	0	30.5	146.3
75	58.1	1.9	35.6	133.7
83	75.3	2.0	48.0	120.0
92	78.5	4.7	45.0	108.8
103	85.0	11.4	45.0	97.1

Note: The 2nd Order was observed from 30 millimicrons through 75 millimicrons and reached a peak (relative efficiency) of 46.0% at 42 millimicrons.

Table XXX. Efficiency measurements of test ruling NRL 41 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
71	54.6	0.7	40.2	140.2
76	55.6	0.6	42.6	131.7
78	54.6	0.6	47.9	128.5
83	66.0	0.7	55.3	120.0
90	69.2	0.6	51.0	111.2
92	75.2	1.3	59.7	108.8
95	90.3	0.0	76.4	105.3
101	87.8	0.4	62.2	99.0
105	78.9	0.4	60.6	95.4
110	81.3	0.7	56.0	90.7
114	81.9	0.7	51.9	87.3

Note: The 2nd Order was observed through most of the spectral range with a peak relative efficiency of 2.1% at 105 millimicrons.

Table XXXI. Efficiency measurements of test ruling NRL 42 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
56	57.2	0.0	26.2	177.4
61	62.4	0.0	36.4	164.3
63	56.1	0.0	38.7	159.3
68	77.7	0.0	60.4	146.3
71	79.6	0.0	67.2	140.2
76	77.8	0.6	69.2	131.7
83	93.3	0.7	92.7	120.0
90	101.2	1.3	86.9	111.2
92	100.7	1.3	89.3	108.8
95	116.5	1.5	100.8	105.3
99	110.3	1.5	94.9	101.0
103	110.6	1.4	90.7	97.1

Note: The 2nd Order was observed through most of the spectral range and reached a high relative efficiency of 21.6% at 56 millimicrons.

Table XXXII. Efficiency measurements of test ruling NRL 43 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th. Order	1st Order	Wavenumber in Kilokaysers
51	37.9	0	34.6	197.0
55	36.2	0	38.0	181.0
63	36.1	0	40.4	159.3
70	49.0	0	52.3	142.8
76	52.5	0	53.7	131.7
83	68.0	3.3	61.3	120.0
92	74.5	6.7	57.7	108.8
103	81.4	10.7	45.7	97.1

Note: The 2nd Order was visible throughout almost the entire spectral range with a high relative efficiency of 3.6% at 103 millimicrons.

Table XXXIII. Efficiency measurements of test ruling NRL 44 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th. Order	1st Order	Wavenumber in Kilokaysers
30	14.9	0	6.4	333.3
37	12.0	5.3	20.0	268.0
43	11.7	4.0	41.5	230.5
51	8.3	7.8	55.0	197.0
55	5.9	0.7	39.7	181.0
68	15.6	1.9	63.3	146.3
76	24.1	4.9	57.4	131.7
83	38.0	8.7	66.7	120.0
92	49.0	15.8	68.8	108.8
103	58.6	23.6	58.6	97.1
111	67.4	30.9	53.3	90.2
122	61.8	41.2	48.2	82.0

Note: The 2nd Order was observed throughout the entire efficiency measurement and reach a peak relative efficiency of 58.7% at 37 millimicrons.
The 3rd Order was observed from 30 through 51 millimicrons and from 92 through 122 millimicrons.

Table XXXIV. Efficiency measurements of test ruling NRL 45 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th. Order	1st Order	Wavenumber in Kilokaysers
30	8.5	4.3	6.4	333.3
35	4.6	3.1	9.2	286.0
37	6.7	4.0	13.3	268.0
46	6.8	4.2	15.8	217.5
51	8.3	5.9	24.2	197.0
55	7.9	4.5	24.8	181.0
61	9.3	4.5	30.8	164.3
70	15.9	4.7	51.7	142.8
75	15.0	3.8	51.2	133.7
79	17.1	3.7	56.1	127.1
83	21.3	5.3	64.0	120.0
92	25.1	9.1	64.0	108.8
103	30.0	15.0	57.9	97.1
110	32.0	20.0	56.0	90.7
117	34.6	22.4	46.1	85.1
122	35.3	24.1	43.5	82.0

Note: (1) The 2nd Order was observed through the entire spectral range with a peak relative efficiency of 33.4% at 37 millimicrons.
(2) The 3rd Order was observed from 46 through 61 millimicrons and from 103 through 122 millimicrons.
(3) The 4th Order was observed from 46 through 55 millimicrons.

Table XXXV. Efficiency measurements of test ruling NRL 46 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
30	22.4	4.3	13.8	333.3
34	12.9	4.0	12.9	294.0
37	12.0	6.7	10.7	268.0
46	21.0	11.6	27.4	217.5
51	20.1	9.5	37.9	197.0
55	19.0	5.9	36.2	181.0
61	23.5	3.2	35.2	164.3
68	22.1	3.9	63.0	146.3
76	39.5	2.5	64.8	131.7
83	53.4	5.3	73.3	120.0
92	58.4	9.4	73.8	108.8
95	53.4	6.0	59.1	105.3
101	52.5	6.5	47.5	99.0
103	50.0	7.9	45.7	97.1

Note: (1) The 2nd Order was observed throughout the spectral range with a peak relative efficiency of 62.7% at 37 millimicrons.

(2) The 3rd Order was observed from 46 through 55 millimicrons.

Table XXXVI. Efficiency measurements of test ruling NRL 47 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
55	30.9	0.0	41.7	181.0
61	33.0	0.0	48.0	164.3
63	33.0	0.0	47.0	159.3
68	48.7	0.0	62.3	146.3
71	51.4	0.0	66.5	140.2
76	50.0	0.0	59.2	131.7
83	65.4	0.7	69.4	120.0
90	65.4	0.6	62.2	111.2
93	66.8	0.0	59.0	107.8
95	79.8	0.8	69.1	105.3
99	77.9	1.5	62.2	101.0

Table XXXVII. Efficiency measurements of test ruling NRL 48 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
63	33.0	0.0	26.1	159.3
68	44.9	0.0	36.4	146.3
70	45.1	0.0	40.4	142.8
75	44.4	0.0	40.6	133.7
79	48.2	0.0	42.7	127.1
83	57.3	0.0	48.0	120.0
88	58.4	0.0	46.2	113.7
92	63.0	0.0	46.0	108.8
95	76.7	0.0	49.5	105.3
98	67.7	0.0	46.7	102.4
101	59.9	0.0	38.2	99.0

Table XXXVIII. Efficiency measurements of test ruling NRL 49 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
30	19.2	-	-	333.3
68	46.1	0.0	17.5	146.3
70	34.4	0.0	14.6	142.8
76	34.6	0.0	16.7	131.7
83	55.3	0.0	31.4	120.0
90	56.6	0.0	30.2	111.2
92	54.4	0.0	28.2	108.8
95	70.7	3.8	35.4	105.3
99	65.9	0.0	31.1	101.0
100	61.3	0.0	30.7	99.5

Note: The 2nd Order was observed at 30, 90, and 95 millimicrons

Table XXXIX. Efficiency measurements of test ruling NRL 50 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
30	47.9	8.5	12.8	333.3
34.5	43.1	4.6	15.4	290.0
39	68.4	7.9	29.0	258.5
46	60.0	5.3	46.3	217.5
51	43.8	3.0	38.5	197.0
55	33.8	2.4	31.7	181.0
62	34.6	1.3	37.0	161.3
70	51.7	3.3	43.1	142.8
76	52.5	4.3	46.3	131.7
83	66.7	9.3	50.0	120.0
92	73.8	13.4	44.3	108.8

Note: The 2nd Order was observed throughout the spectral range with a peak relative efficiency of 44.7% at 39 millimicrons.

Table XL. Efficiency measurements of test ruling NRL 51 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilokaysers
68	22.1	0.0	22.1	146.3
71	23.7	0.6	23.7	140.2
76	23.4	0.6	25.9	131.7
83	39.3	1.3	36.0	120.0
90	40.9	1.9	32.7	111.2
92	43.9	1.7	36.7	108.8
95	55.6	0.8	43.6	105.3
101	48.9	2.2	34.5	99.0
105	47.2	2.8	33.8	95.4
110	49.3	4.0	35.3	90.7
115	55.0	5.0	33.1	87.3
122	56.5	11.2	30.0	82.0

Note: The 2nd Order was observed throughout the spectral range with a high relative efficiency of 6.5% at 68 millimicrons.

Table XLI. Efficiency measurements of test ruling NRL 52 relative to "Standard (10/23/64)" gold reflectance curve.

Wavelength in Millimicrons	Relative Efficiencies % Unruled Area	0th Order	1st Order	Wavenumber in Kilo aysers
92	81.9	4.7	28.2	108.8
95	91.0	8.3	27.8	105.3
101	82.7	7.2	22.3	99.0
105	79.6	7.0	18.3	95.4
110	78.2	11.9	17.9	90.7
115	79.4	15.0	19.4	87.3
118	83.7	16.4	17.6	84.6
122	83.5	20.0	18.8	82.0
128	84.1	23.3	14.8	78.4
134	86.4	26.1	15.2	74.4
140	87.9	35.3	14.7	71.5
146	87.4	32.5	13.7	68.3

Note: The 2nd Order was observed throughout the spectral range and reached a peak relative efficiency of 15.8% at 95 millimicrons.

3. "Standard (10/23/64)" Curve

Table XLII reports the reflectance measurements of several different Au films. The first column has the values read from a published curve (R. Canfield, G. Hass, and W. Hunter. J. Phys. 25, 127, 1964). The second column reports the reflectance of the transfer film used for NRL 23. The third column reports the film reflectance of NRL 25. The fourth column reports the film reflectance of a transfer coat of gold deposited by Joule heating. The fifth column is for a transfer coat of an alloy film of 97% Au - 3% Ge prepared by electron gun deposition.

The highest value for each spectrum line in the table has been chosen for the corresponding point of the "Standard (10/23/64)" curve.

Near the end of the year, W. Hunter remeasured NRL 23 and found values near those reported by Canfield, Hass, and Hunter. Thus, the absolute values found in October are suspect. Similar values were measured for NRL 23 on different days and by different observers so any error was a persistent and consistent one. And in the case of gratings 24 and 28, the cumulative spectral efficiency measurements at 55 nm exceeded the mirror reflectance value of Canfield, Hass, and Hunter.

It seems unlikely that any grating in gold will ever exhibit an efficiency in one order that is greater than the "Standard (10/23/64)" curve value. This curve could be regarded as near the ultimate

of possible success. The efficiency data in the previous section was therefore plotted as the ratio of the absolute efficiency to the "Standard (10/23/64)" reflectance.

Table XLII. Absolute reflectance of several gold films

Wavelength in Nanometers	Thin, Fast Canfield Hass, Hunter *	Transfer Coats, Bausch & Lomb Electron Gun NRL 23	Electron Gun NRL 25	Joule Heat Deposit	Electron Gun Au_{97} Ge_3
30	3.0	4.7**	---	3.3	3.8
32	3.7	5.6	---	---	---
35	5.0	---	---	---	6.6
37	8.0	---	---	6.4	---
38	8.0	7.6	---	---	7.1
42	7.5	---	---	7.8	---
45	7.3	7.9	6.9	---	---
46	7.5	---	---	7.7	---
48	9.0	---	---	---	8.4
51	12.0	16.9	13.3	12.1	11.5
55	16.5	29.0	20.2	16.2	16.5
58	15.7	---	---	---	16.3
61	12.5	---	16.6	13.7	---
63	11.0	23.0	15.6	---	13.6
68	9.9	---	---	9.7	10.9
69	9.6	15.4	11.3	---	---
70	9.6	15.1	11.8	---	---
71	9.9	---	---	---	11.0
76	10.7	16.2	12.3	11.2	---
79	11.5	---	13.2	---	11.8
80	11.7	16.3	---	---	---
83	12.0	15.0	14.0	13.1	12.0
90	13.0	15.9	---	12.5	---
92	12.9	14.8	14.9	---	12.5
95	12.8	12.2	---	13.8	---
96	13.0	---	13.3	---	---
98	13.5	---	---	---	11.7
99	13.6	---	---	12.9	---
103	14.0	12.0	14.0	12.7	11.5

*Canfield, Hass, and Hunter. J. Phys. 25 pp. 124-129 (1964). Values have here been read from Fig. 6 on page 127.

**The absolute value of 4.7% for the reflectance at 30 millimicrons came from data from NRL 21 film, (also Electron Gun Transfer).

"STANDARD" GOLD REFLECTANCE CURVE

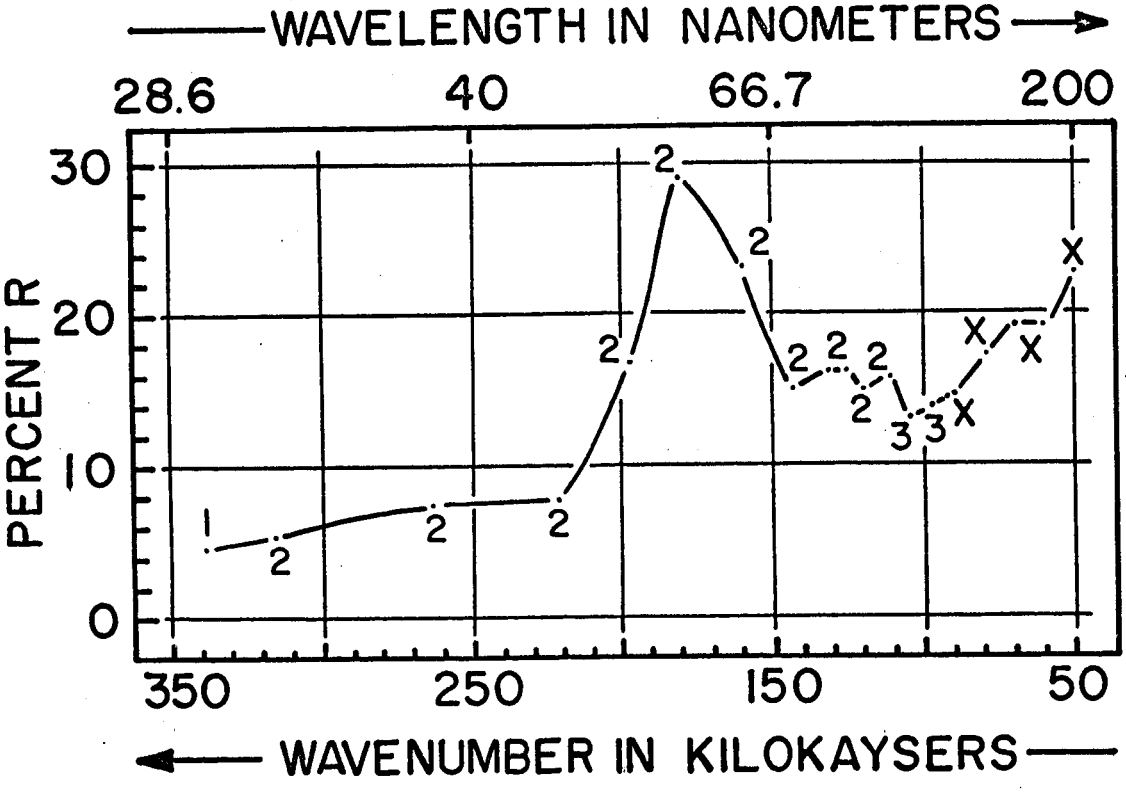
CURVE COMPRISED OF MAXIMUM VALUES OBTAINED FROM DATA TAKEN BY W. ANDERSON AND F. MOONEY ON 10/23/64 AT NAVAL RESEARCH LAB.

1 FILM USED FOR NRL RULING 21

2 FILM USED FOR NRL RULING 23

3 FILM USED FOR NRL RULING 25 & 26

X PUBLISHED VALUES, R. CANFIELD, G. HASS AND W. R. HUNTER J. PHYS. 25, 127 (1964)



4. Electron Micrographs of Glass Surfaces

On one of the trips taken to the Naval Research Laboratory, the reflectance of two monitor films was measured. The object of the measurement was to decide whether the gold deposited in that particular filming run efficiently reflected 304 A and whether a grating should be ruled in it. These monitor films were coated simultaneously, one on a poorly shined 50 mm square plate and the other on an optically polished 80 mm round plate. The 50 mm square reflected under 0.1% whereas the well-polished plate reflected over 1%.

The hypothesis was that surface polish was important to short wavelength reflectance. The following electron micrographs are a set that was prepared following this experience.

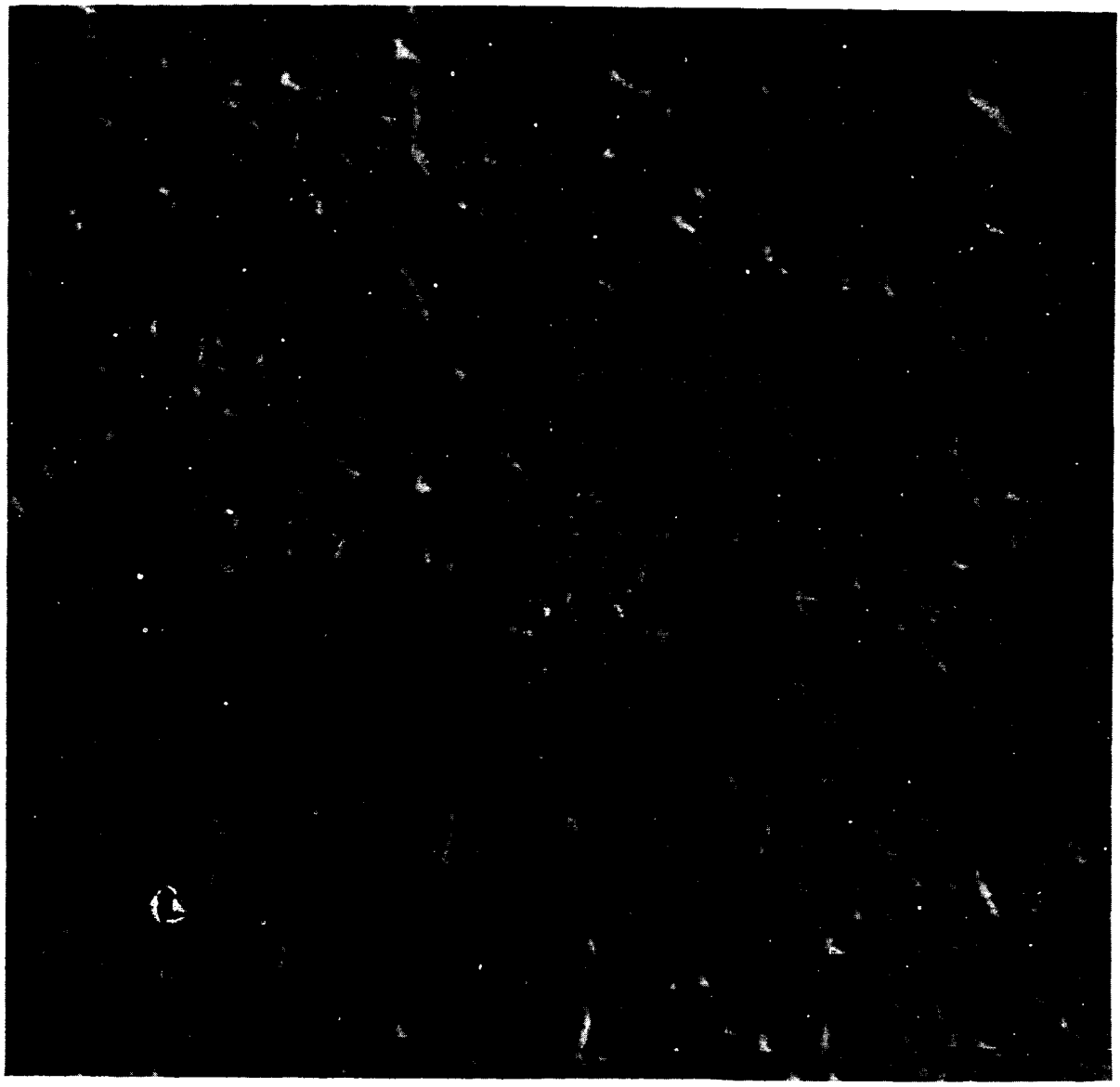
The first four of these pictures were made after a collodion replication procedure. At this point, a doubt developed that the surfaces were as smooth as they appeared to be.

The next two pictures are of shadows cast onto an aluminum film replica. The same considerations that required using non-organic films for grating specimen replicas were thus tested on polished surfaces.

There is clear evidence that surface imperfections are lost by the collodion, both for the optical polish and for the under-liquid polish surfaces.

The final picture in this section was made from an aluminum film replica that was lifted without being backed by tape. There is a fine surface texture observed here that was not observed on any other picture of polished glass. Further work needs to be done.

The need for further work is also emphasized by the comparatively good reflectance of the film used for NRL 31. The substrate for this grating was poorly polished. But the reflectance of the film and the efficiency of the grating ruled in it were good.



1 μ

Electronmicrograph showing glass surface previous to coating and ruling NRL grating.

Picture Data

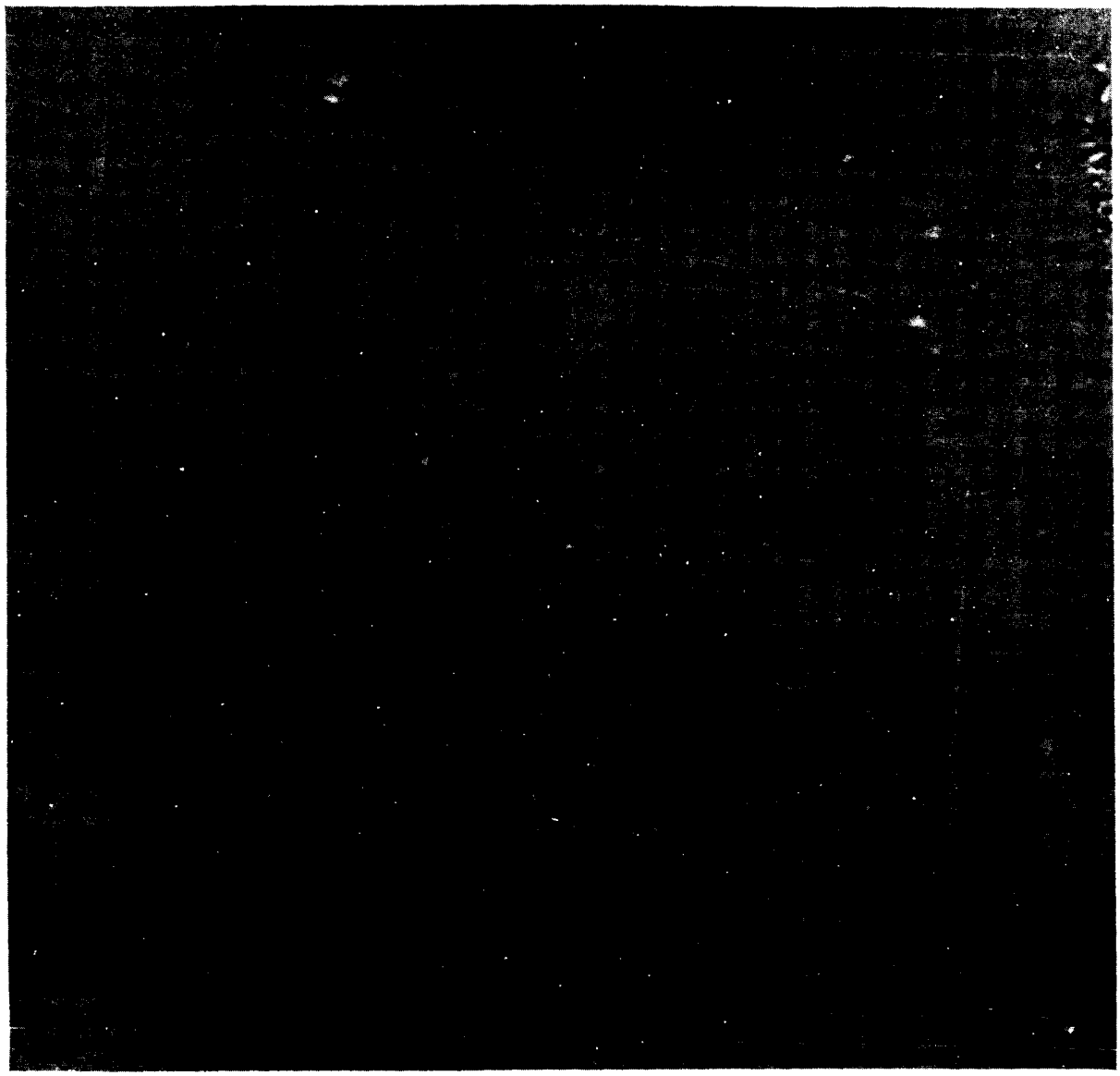
Film: N111 #1, 7-22-64

Collodion Substrate: 1%

Substrate Data

Material: Glass

Polish: Pitch
Incomplete Shine



1μ

Electronmicrograph showing glass surface previous to coating and ruling NRL grating.

Picture Data

Film: N119 #18, 8-20-64

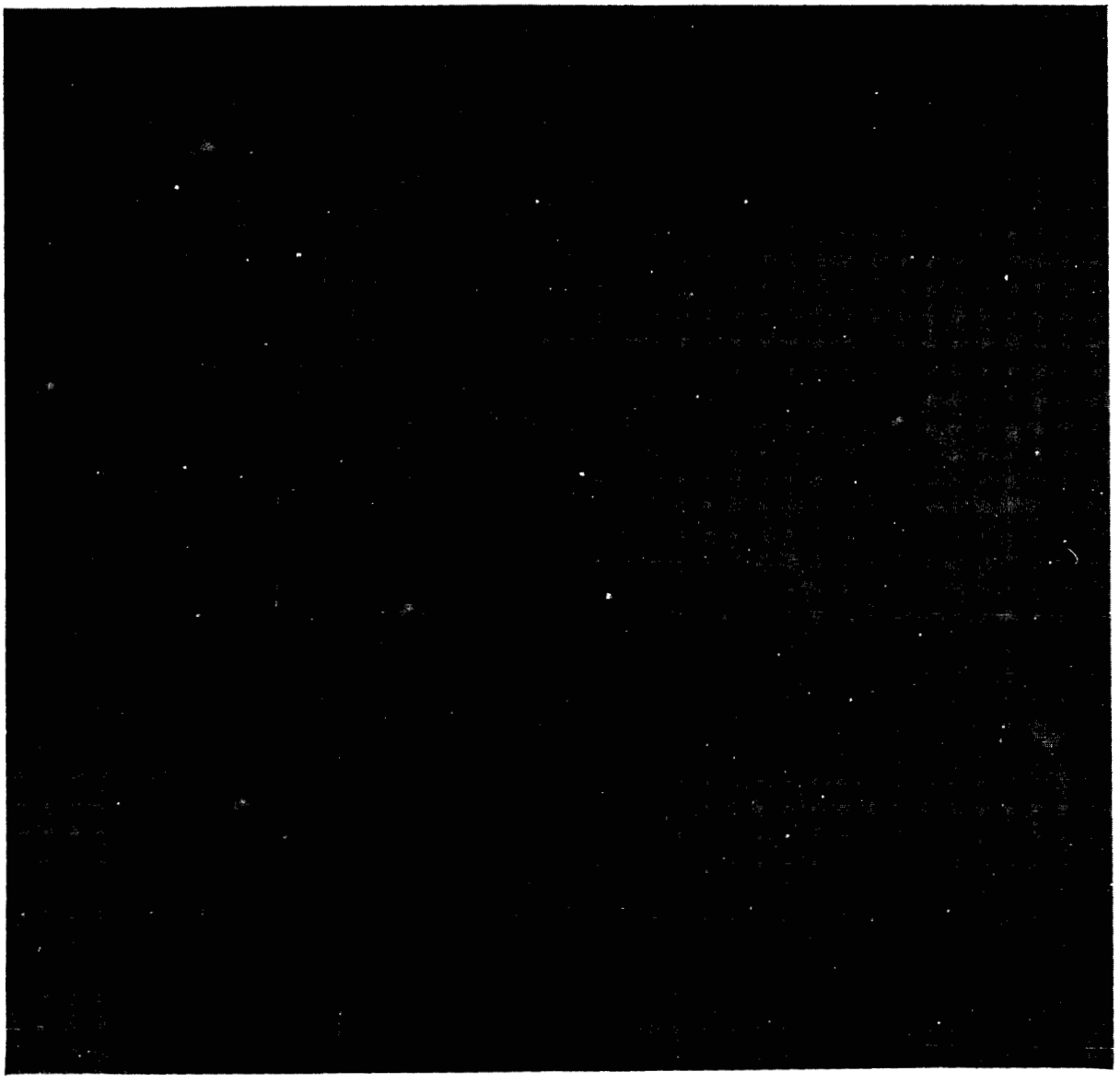
Collodion Substrate: 1%

Shadow: Pt-C

Substrate Data

Material: Glass

Polish: Pitch, Optical



1μ

Electronmicrograph showing glass surface.

Picture Data

Film: N146 #4, 10-16-64

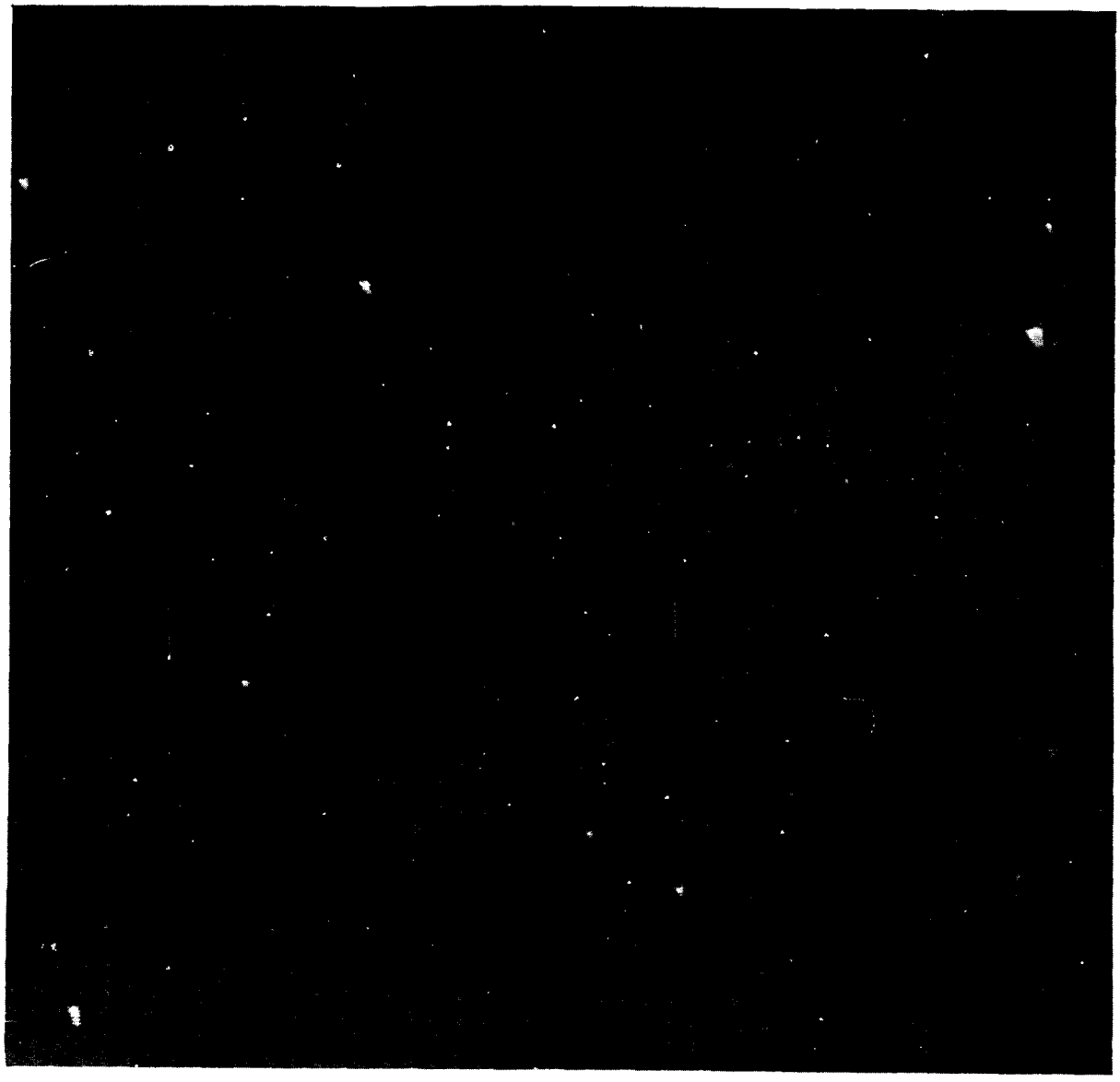
Substrate: Collodion 1%

Shadow: Pt-C

Substrate Data

Material: Glass

Polish: Optical Pitch
(no defects with 8X Loupe)



1 μ

Electronmicrograph showing glass surface.

Picture Data

Film: N150 #29, 10-22-64

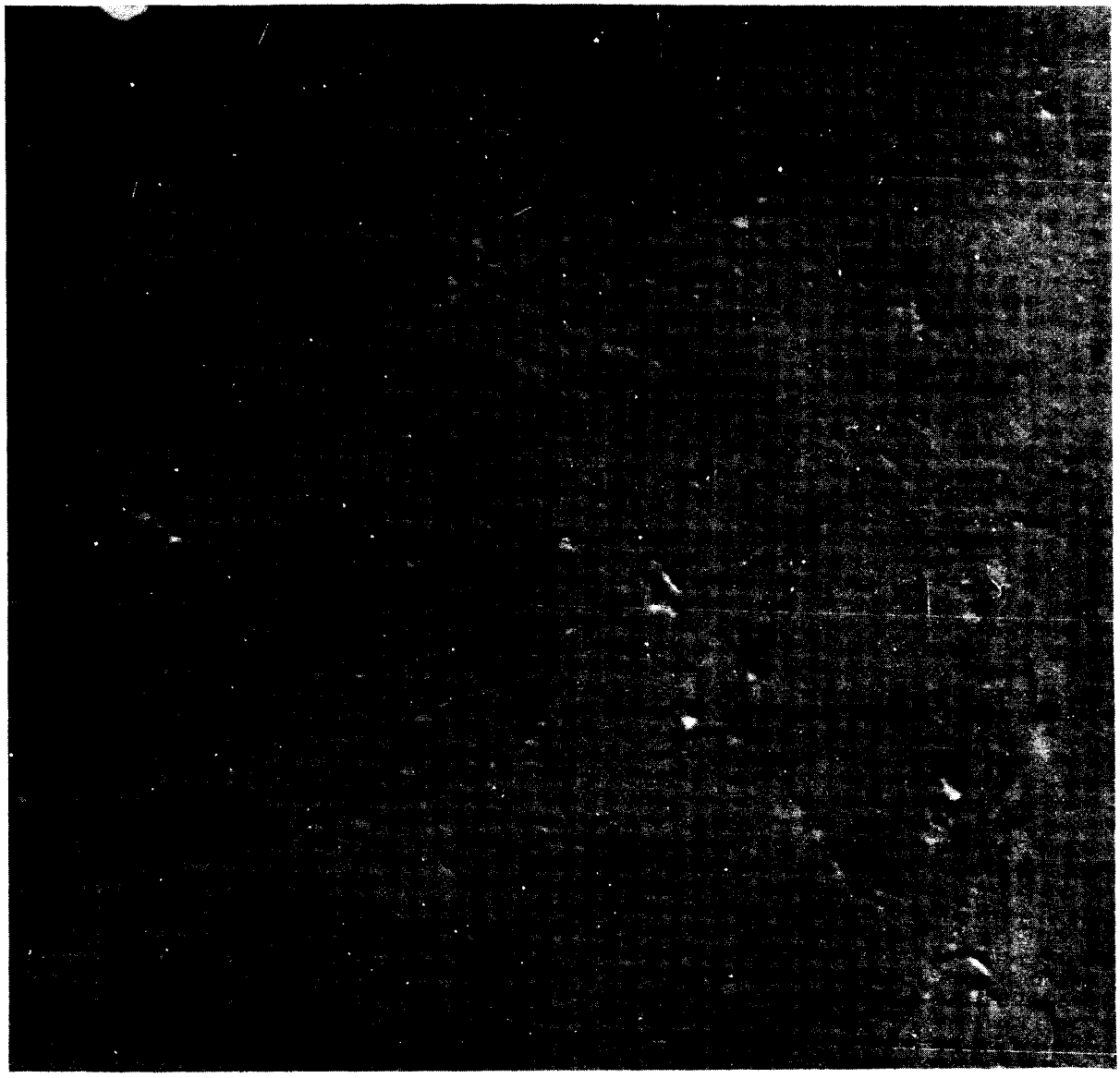
Substrate: Collodion 1%

Shadow: Pt-C

Substrate Data

Material: Glass

Polish: Under Liquid
(work done at Herron Opt. Co.)



1μ

Electronmicrograph showing glass surface.

Picture Data

Film: N146 #21, 10-16-64

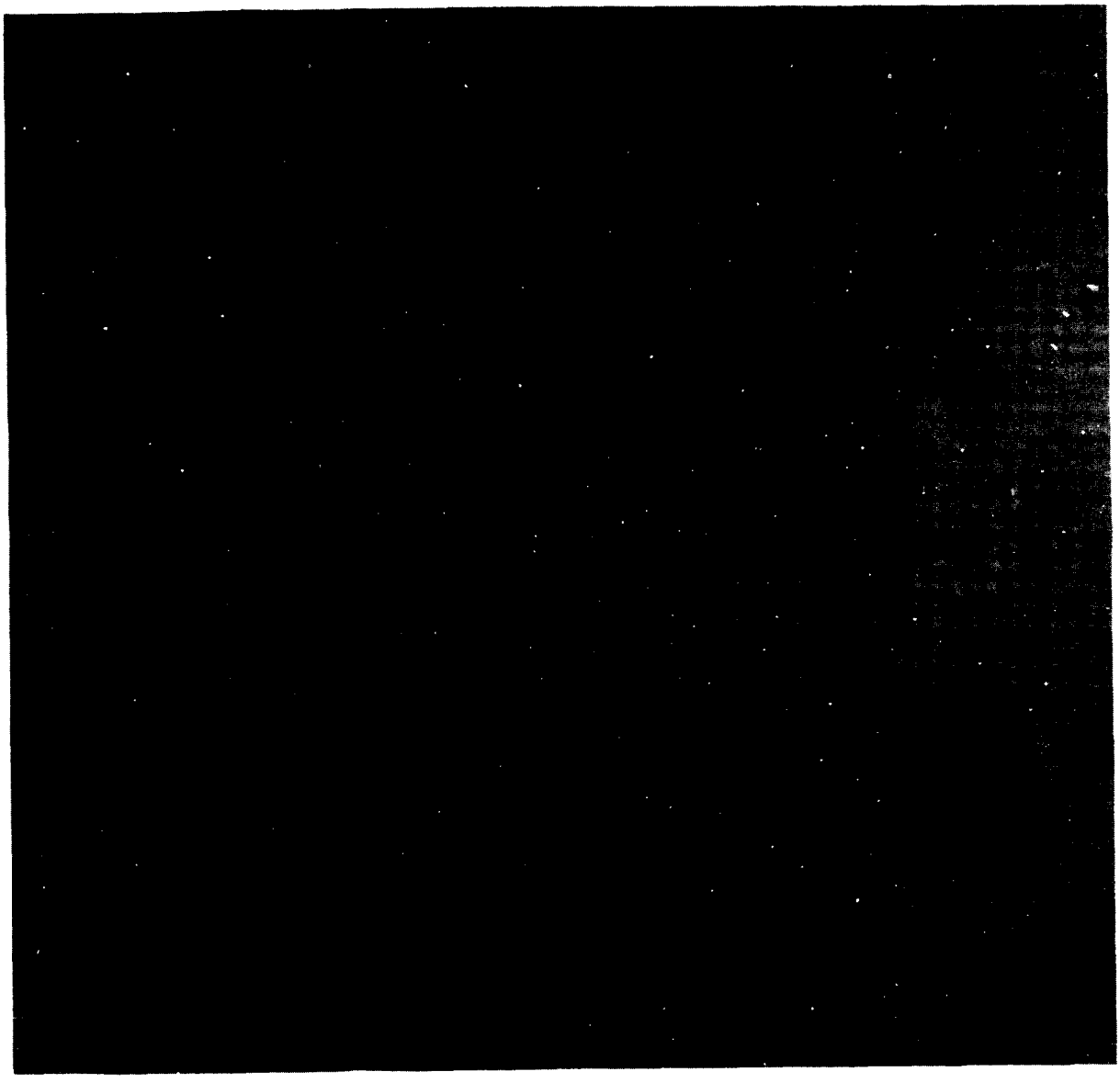
Substrate: Aluminum Film lifted with tape

Shadow: Pt-C

Substrate Data

Material: Glass

Polish: Optical Pitch (no defects with 8X loupe)



1μ

Electronmicrograph showing glass surface.

Picture Data

Film: N146 #28, 10-16-64

Substrate: Aluminum film lifted with tape

Shadow: Pt-C

Substrate Data

Material: Glass

Polish: Under Liquid
(work done at Herron Opt. Co.)

1 μ

Electronmicrograph of highly polished glass surface. This surface is so smooth that the normal procedure of lifting the replica film specimen with tape was avoided. The imprint of the glue from the tape and/or shear forces that develop when applying the tape are expected to modify the appearance of the polish.

Picture Data

Film: N149 #12, 10-20-64

Substrate: Aluminum Film

Shadow: Pt-C

Substrate Data

Material: Glass

Polish: Under Liquid

(work done at Herron Opt. Co.)

5. Report and Electron Micrographs of Chromium Films

This section is included for completeness. A chromium connecting film has been used under almost every gold film that was ruled for this contract. The thickness of some typical chromium underlayers was checked interferometrically and found to be between 60 and 80 nm. The films ruled for the contract have been classified in Table XLIII according to their chromium thickness by looking at their second surface (glass interface). If it is yellow, the chromium thickness is $\ll 70$ nm. If it is pink, the thickness is listed as <70 nm. If it is steel with a pink cast, the thickness is listed as ~ 70 nm. If the interface has the appearance of polished steel, the thickness is listed as >70 nm.

There may be some desire to know what the chromium film surfaces look like so electron micrographs of them on optically polished glass and on under-liquid polished glass for thin, average, and thick chromium deposits are presented here.

Table XLIII. Estimated chromium under-layer thickness relative to an average thickness of 70 nm.

NRL #	Thickness	NRL #	Thickness
1	$\ll$	23	$<$
2	$\sim$	24	$<$
3	$<$	25/26	$<$
4	$\ll$	27	$\sim$
5	$>$	28/29	$>$
6	$\sim$	30	$\sim$
7	$\sim$	31	$\sim$
8	$\sim$	32	$\sim$
9	$\sim$	33/34	$<$
10	$\sim$	35/36	$\sim$
11	$>$	37/38	$\sim$
12	$\sim$	39/40	$>$
13	$>$	41/42	$>$
14	$\sim$	43	$\sim$
15	$\sim$	44	$\sim$
16	$>$	45	$>$
17	$\sim$	46	$<$
18	$\sim$	47	$<$
19	$\sim$	48	$<$
20	$\ll$	49	$\ll$
21	none	50	$\ll$
22	$\ll$	51	$<$

1μ

Electronmicrograph showing the surface of chromium on an optically-polished glass substrate.

Picture Data

Film: N163 #4, 11-4-64

Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

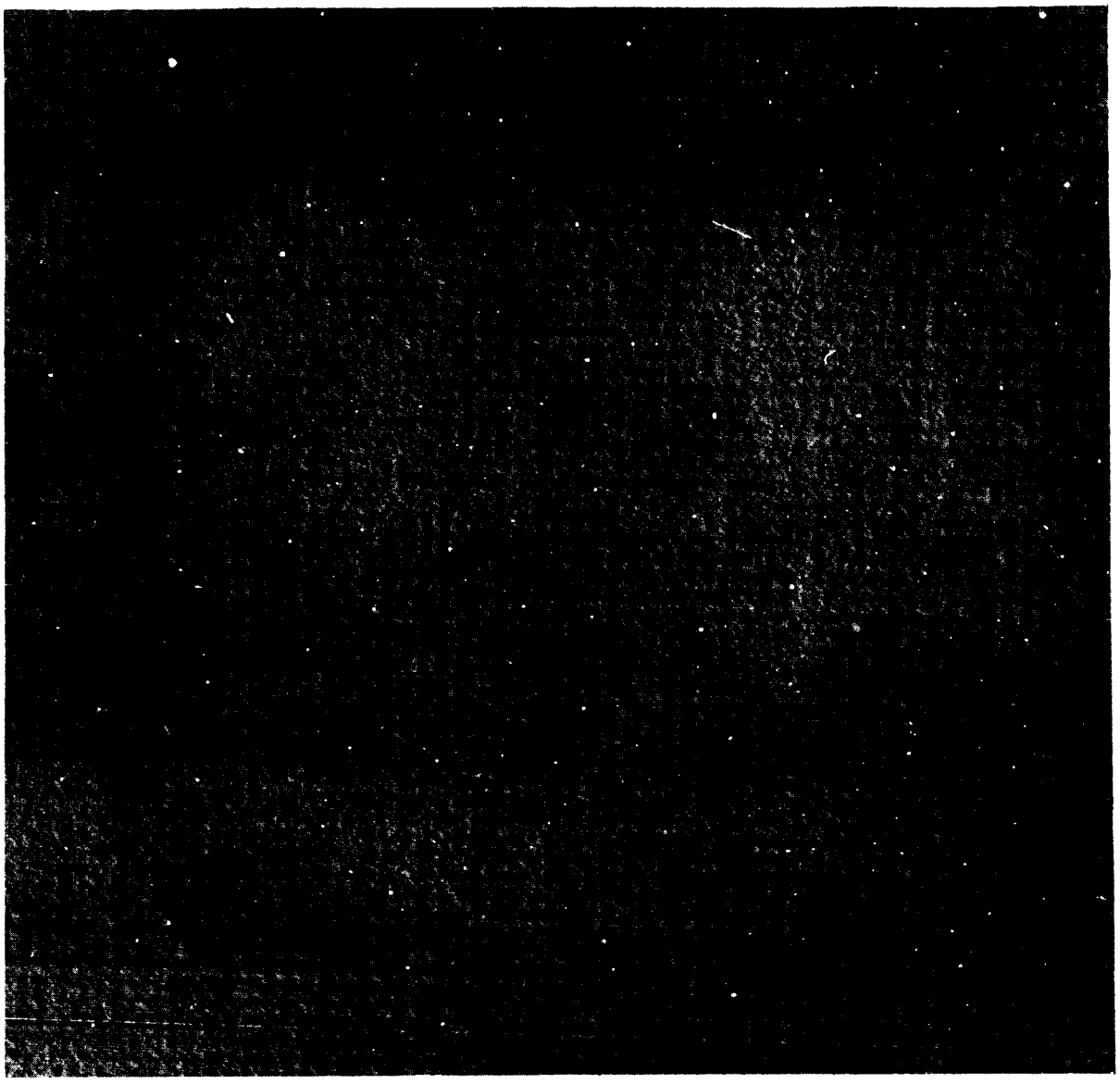
Chromium Deposition

Power: Electron Gun

Mtl. Form: Solid Piece

Cleaning: HCl

Thickness: $<$600 A



1μ

Electronmicrograph showing the surface of chromium on an optically-polished glass substrate.

Picture Data

Film: N163 #9, 11-14-64

Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

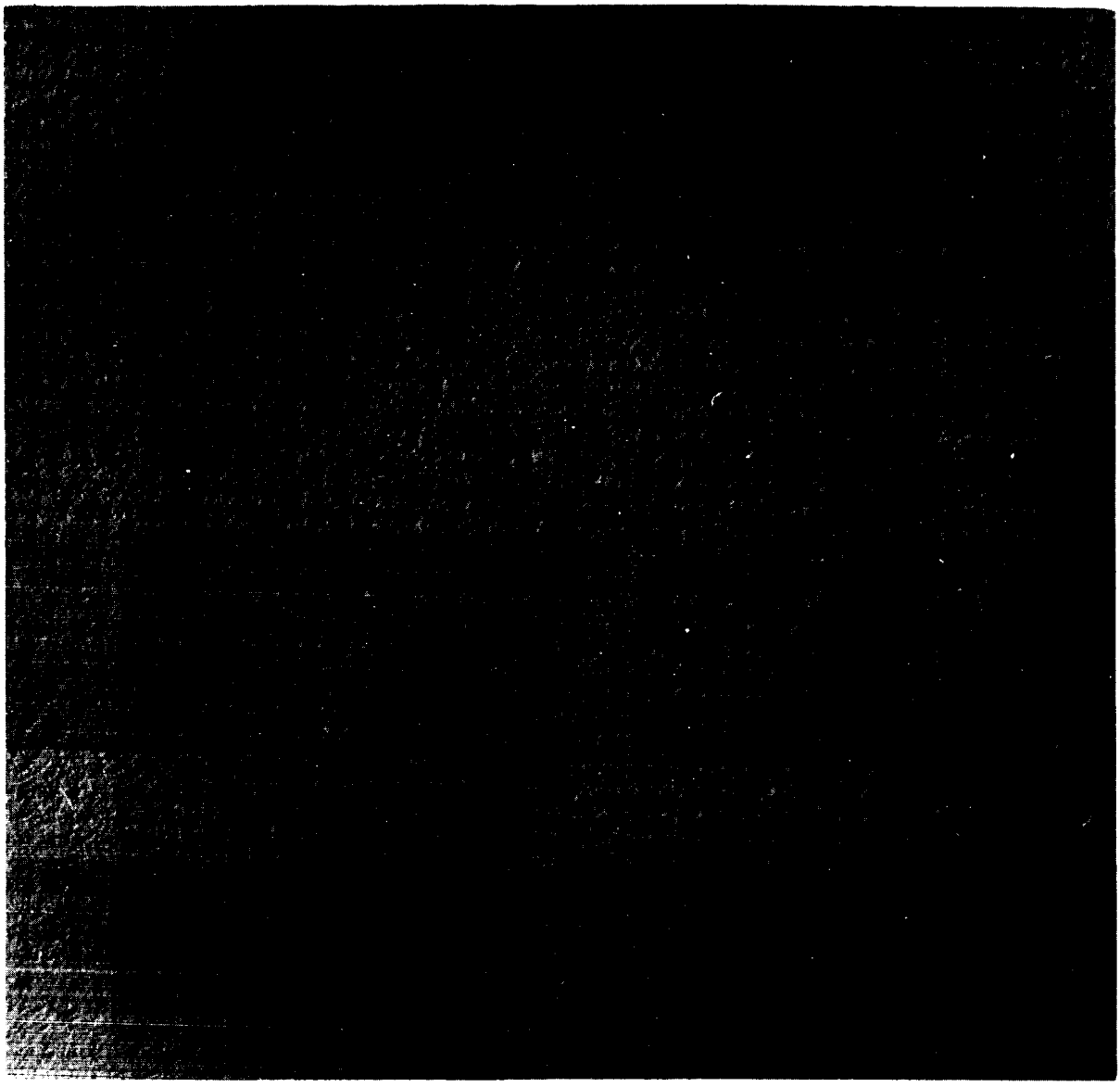
Chromium Deposition

Power: Electron Gun

Mtl. Form: Solid Piece

Cleaning: HCl

Thickness: 600-800 A



1μ

Electronmicrograph showing the surface of chromium on an optically-polished glass substrate.

Picture Data

Film: N163 #12, 11-14-64

Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

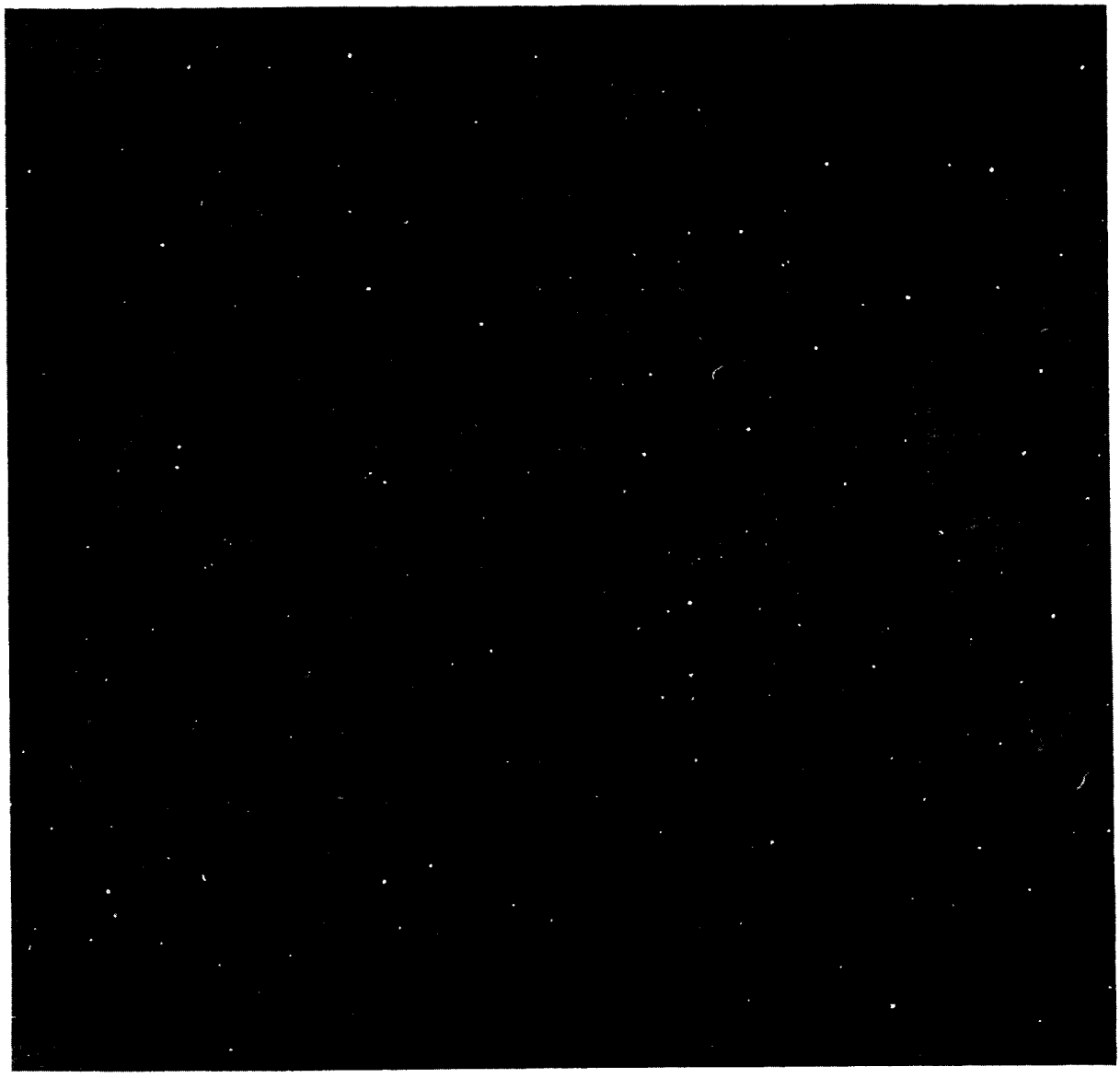
Chromium Deposition

Power: Electron Gun

Mtl. Form: Solid Piece

Cleaning: HCl

Thickness: > 1000 A



1μ

Electronmicrograph showing the surface of chromium on an under-liquid polished glass substrate.

Picture Data

Film: N163 #19, 11-14-64

Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

Chromium Deposition

Power: Electron Gun

Mtl. Form: Solid Piece

Cleaning: HCl

Thickness: <600 A

1μ

Electronmicrograph showing the surface of chromium on an under-liquid polished glass substrate.

Picture Data

Film: N163 #21, 11-14-64

Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

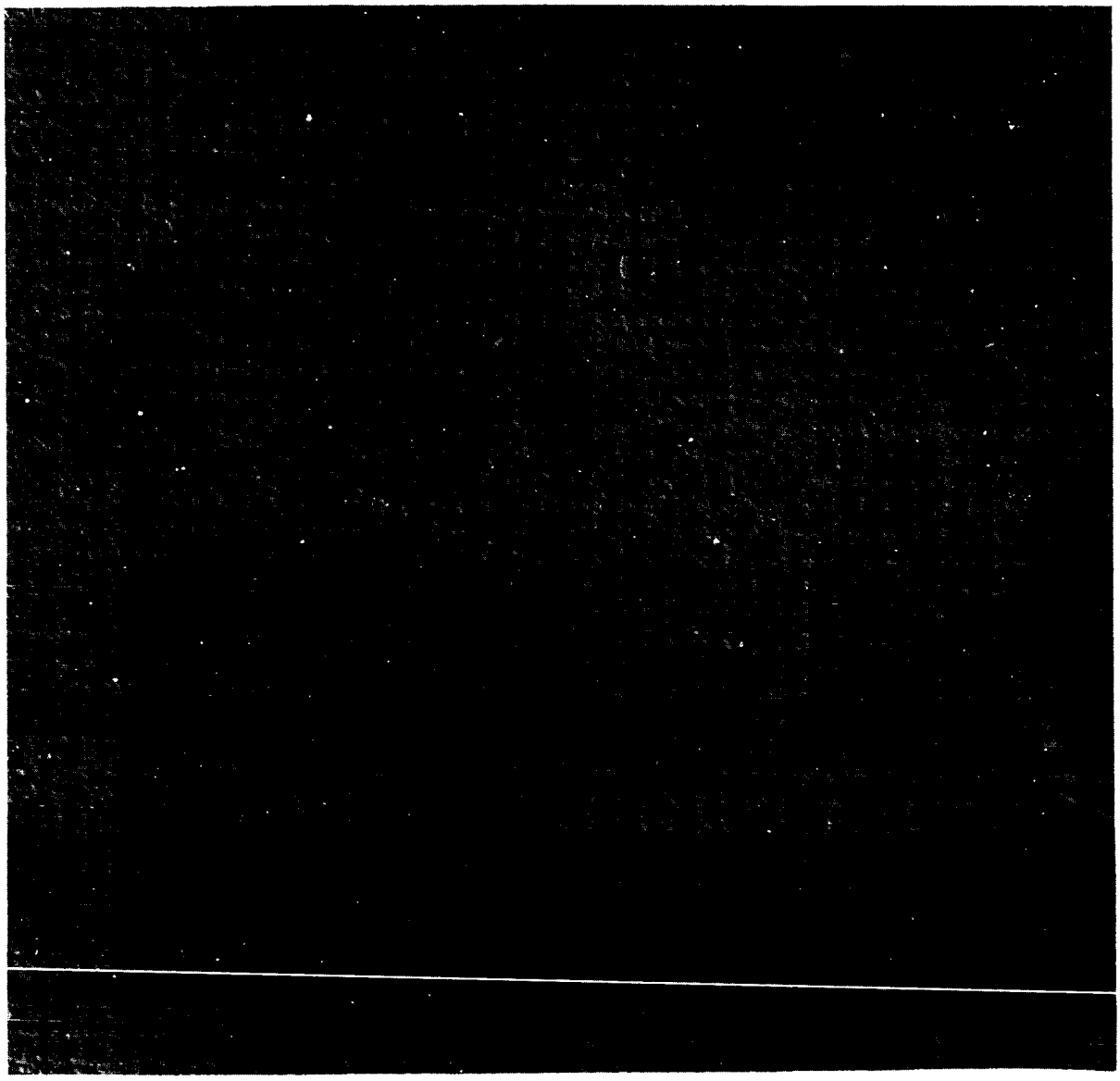
Chromium Deposition

Power: Electron Gun

Mtl. Form: Solid Piece

Cleaning: HCl

Thickness: 600-800 A



1μ

Electronmicrograph showing the surface of chromium on an under-liquid polished glass substrate.

Picture Data

Film: N163 #26, 11-14-64

Substrate: Al Film

Shadow: Pt-C

Specimen Film: C

Chromium Deposition

Power: Electron Gun

Mtl. Form: Solid Piece

Cleaning: HCl

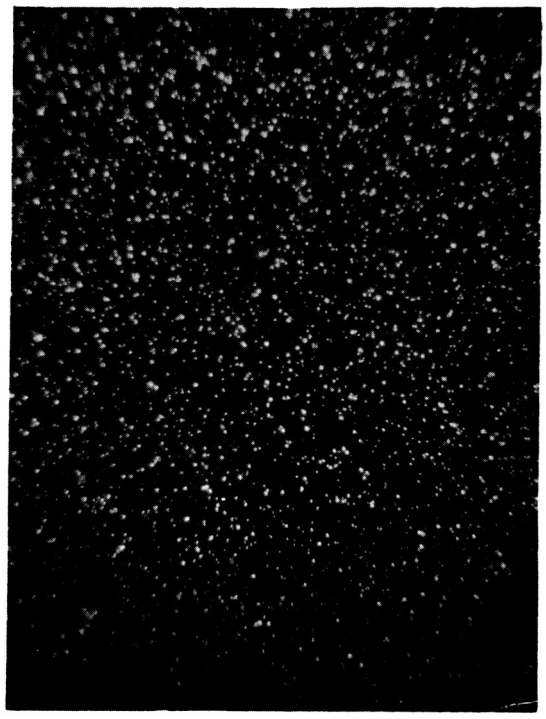
Thickness: >1000 A

6. Surface Study of Gold Films Using Dark-Field Illumination

All of the pictures in this section were taken with a Bausch & Lomb Metallograph on Polaroid film. The magnification, as it appears here, is 150X approximately. The bright scattering centers are minute nuggets of gold that presumably were deposited as lumps rather than as atoms.

There were few particles of dust because 1) the films were supported in an inverted position by the metallograph stage and 2) the surfaces were prepared by covering them with a film of collodion that was stripped just prior to placing a specimen on the stage.

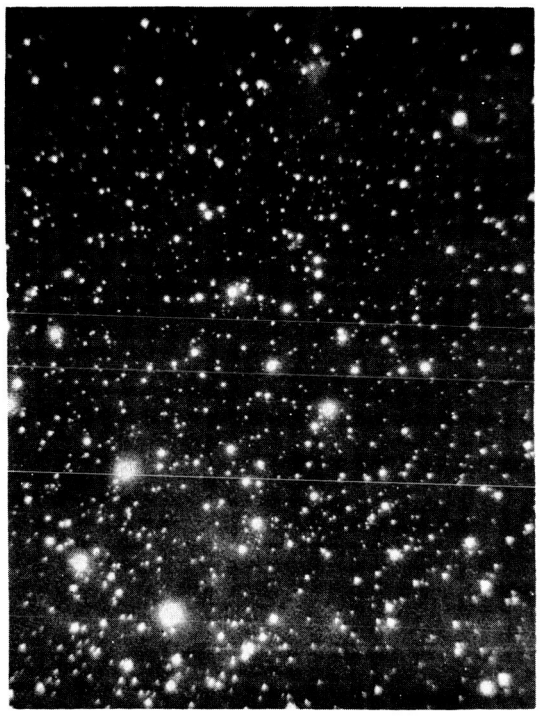
In each case, numerical details of the films can be found by returning to previous reports or to Section 1 of this report and referring to the legend on the picture.



Substrate used for NRL ruling 30.

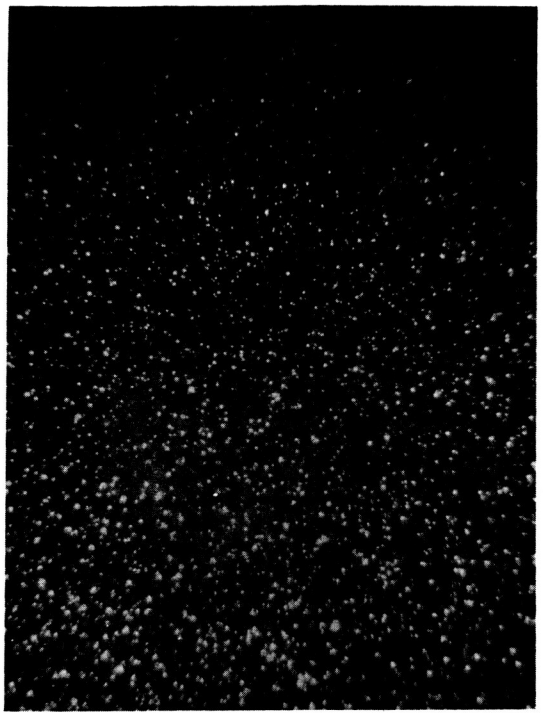
Average deposition conditions; viz.,

First surface film, pure gold,
optically polished substrate,
medium deposition rate,
electron gun vaporization.



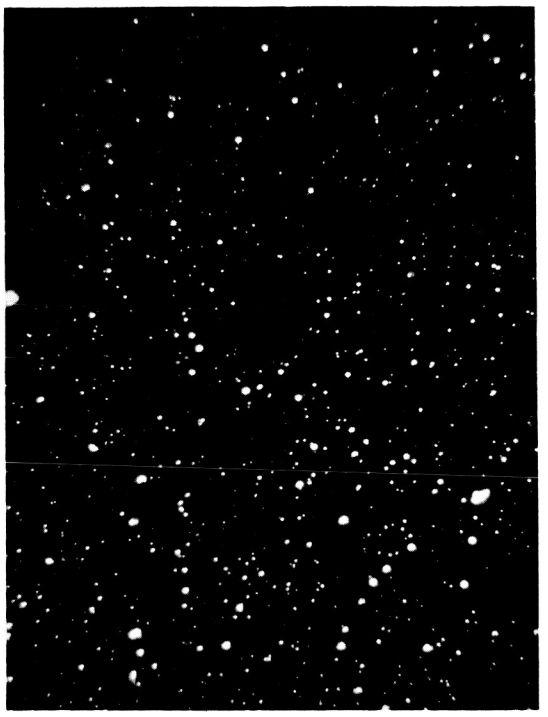
Substrate used for NRL ruling 32.

Eutectic of gold & germanium,
average deposition conditions
in other respects.



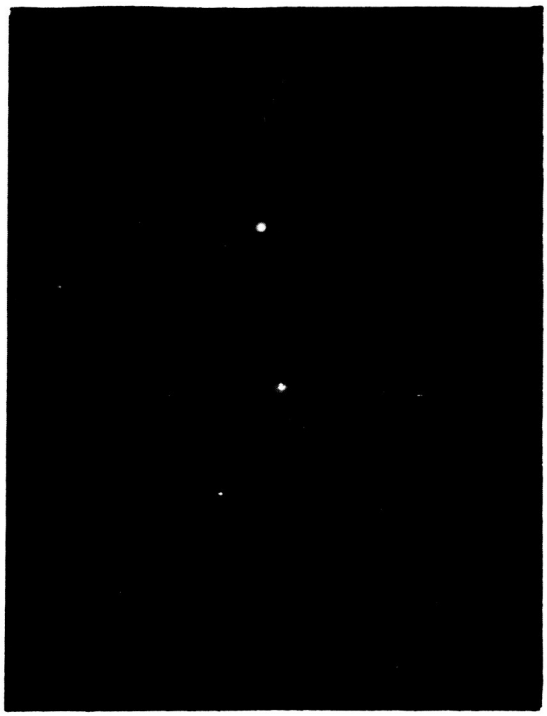
Substrate used for NRL ruling 31.

Incomplete substrate polish,
average deposition conditions
in other respects.



Substrate used for NRL ruling 47.

Superior substrate polish,
average deposition conditions
in other respects.

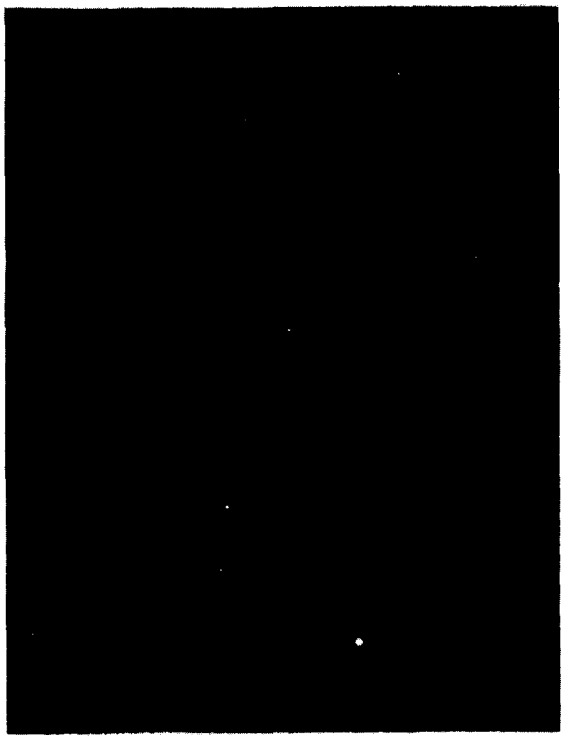


Substrate used for NRL ruling 49.

Joule heated vaporization, thin film; average deposition conditions in other respects.

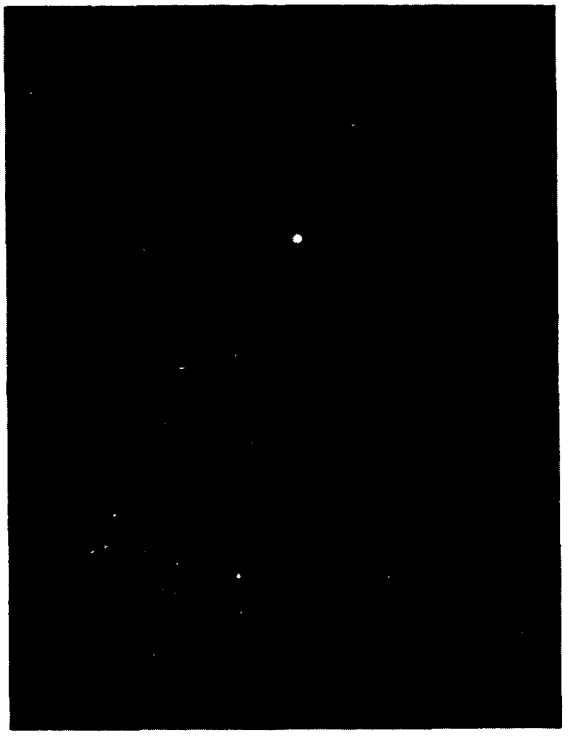
Substrate used for NRL rulings 25 & 26.

Transfer film, rapid electron gun deposition, 2-3 times average thickness, average deposition conditions in other respects.



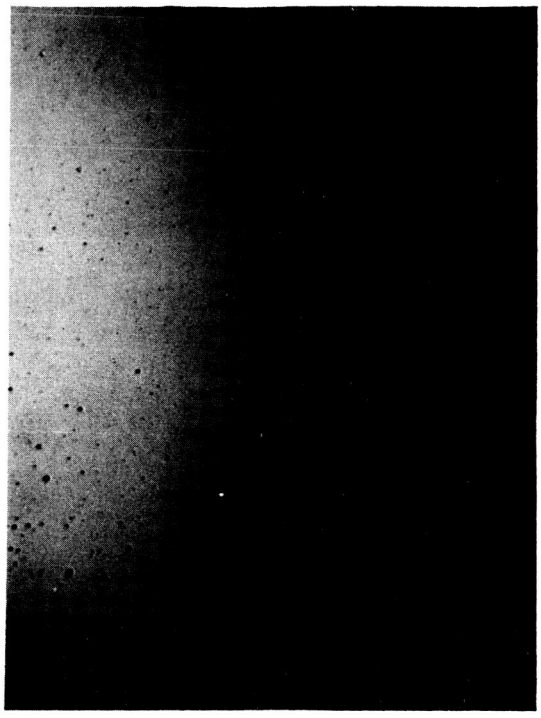
Substrate used for NRL ruling 20.

Rapid Joule-heated vaporization at NRL.



Substrate used for NRL ruling 48.

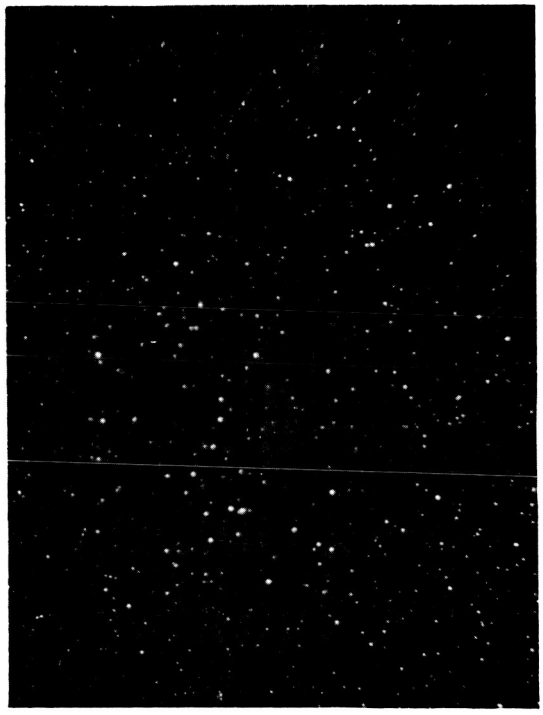
Rapid Joule-heated vaporization at B&L, average deposition conditions in other respects.



Substrate used for NRL ruling 30.

Average deposition conditions.

Same area as is shown by the initial photograph in this section but with oblique bright-field illumination.



Substrate used for NRL ruling 15.

Slow deposition, high pressure; average deposition conditions otherwise.